NEW TECHNOLOGIES FOR INFRASTRUCTURE
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Abstract:
To improve the technologies needed to run efficiently and easily the CTSs at the global level.

Keyword List:
Infrastructure, Fleet management, Human-machine Interface, Remote operation, Energy management.

CONTENT

1. Introduction

1.1 Objectives

***Main objectives**: To improve mobility management in support of sustainable economic growth in Europe and for improving the quality of life of citizens.*

The desire for increased mobility shows no sign of stopping in the EU and, under a scenario of economic growth this looks set to continue. Cybercars, as defined at the beginning of the project, are fully automatic vehicles under control of a management system designed to meet the demand for door to door mobility any time, while avoiding congestion problems (on the roads and in the parkings).

Cybercar Definition

Cybercars are road vehicles with fully automated driving capabilities. A fleet of such vehicles forms a transportation system (called CTS for Cybernetics Transportation System), for passengers or goods, on a network of roads with on-demand and door-to-door capability. The fleet of cars is under control of a central management system in order to meet particular demands in a particular environment. At the initial stages, cybercars are designed for short trips at low speed in an urban environment or in private grounds.

In the long term, cybercars could also run autonomously at high speed on dedicated tracks. With the development of the cybercar infrastructures, private cars with fully autonomous driving capabilities could also be allowed on these infrastructures while maintaining their manual mode on standard roads.

Fleet management is one aspect of this Project that is essential in improving the availability of an alternative to the private car. The cybercars concepts will fill the gaps between existing high quality public transport services and the private car and will therefore provide extra choice for travel which will significantly enhance the quality of life of car owners and non-car owners alike.

The cybercars will also require an efficient information and collection of service fees which would easily be extended to other modes of transportation with simple to use interfaces, in particular with the arrival of a new generation of mobile phones and PDAs. These information and fee services will also extend to other services such as tourist and commercial information on the city and will foster economic growth as well as the quality of life of the citizen.

The **objectives of this WorkPackage** 3 (WP3) are to improve the technologies needed to run efficiently and easily the CTS at the global level. In particular, we want to improve noticeably the performances of the following subsystems:

- Fleet management
- Human-machine interfaces
- Remote operation
- Energy management

1.2 Baseline and improvements of technologies for the infrastructure

Compared to traditional transportation systems which often rely on heavy material infrastructure such as rails or heavy road infrastructures, the CTS will need only a very light one, often no more than the equivalent of a bicycle path, or even just two small tracks for the wheels. Even with such light infrastructures, high transportation needs can be satisfied just by increasing the number of vehicles when needed.

On the other hand, the road infrastructure is replaced by a non-material infrastructure based on information and in particular on telecommunications. These telecommunication networks are now readily available, even if the bandwidth needed is high (UMTS is now offering at low cost bandwidth of 1 Mb/s and higher capacities are already available). The CTS will use these capabilities to their full extent and there is no need to incorporate new developments for them.

The innovation will be placed on the use of these communication networks in order to perform essentially three tasks : management of the resources, user interface and remote control of the vehicles.

The **management of resources** implies that the vehicles and the infrastructure are optimized globally by a central system which knows in real time the availability and the state of all the resources of the system : vehicles, virtual tracks, parking places, energy stations, man-power,…. Depending on the customer requests, the system must make choices to send commands for the movement of vehicles and for other operations such as recharging of energy in the vehicles, maintenance, redistribution,… These tasks are extremely complex to optimize and require advanced management techniques. Some of these techniques have already been developed for car-sharing systems, in particular in the framework of the EVIAC Project (4th FWP). With the possibilities of automatic displacement of the vehicles, the optimization techniques are needed even more in order to respond immediately to the demand.

Depending on the way the CTS will be designed, the **interfaces with the users** will be more or less complicated. On very simple systems, such as the one in Schiphol where the network is simple and the number of stopping points quite limited, a system of calling buttons such as for the elevators is quite sufficient and easy to understand. However, if the system becomes more complex with a large number of origins/destinations, this system of calling buttons is difficult to implement and costly. The Project will hence develop an interface based on mobile phone technologies and in particular on WAP or similar standards to take advantage of digital short messages and graphic interfaces. However, in order to make the system simple to use and easily understandable by any user, including first time visitors, extreme care has to be taken for the design of these interfaces. It is the aim of this Project to define recommendations which could become a standard at least at the European level for these graphical interfaces. The cybercar interfaces are not limited to mobile phones. We must also have similar interfaces inside the vehicle and at some “stations” or in the homes or offices of the users. In these cases, the interfaces will be on larger graphical screens such as the ones found on micro-computers or “Web-phones”. In these cases, the interfaces will be essentially developed on Web standards using languages such as XML and compatible with existing or under development tools for other transportation systems (public transport and rental cars or car-sharing systems).

All of these interfaces on mobile or fixed units or in the vehicle must also be compatible and easily connected to **other information systems** concerning the city and the purposes of the trip. We think about interfaces with commercial destinations (shops, restaurants, hotels, theatres,….) and also with tourist and cultural information.

The last technology we have developed for the infrastructure is the **remote control of the vehicles** from the central management system. This is needed for the monitoring of the state of the vehicles (location, mode of usage, energy,…) but also for the possibility to remotely drive the vehicles. This is considered as an important back-up function for the automatic driving when a vehicle is stopped for an unknown reason : emergency switch activated by someone, obstacle, hardware or software malfunction,… In these cases, it would be convenient for the operator in the control room to take control of the vehicle and see if he/she can eventually operate it. If the remote driving is possible, then the conflict could potentially be resolved and the vehicle returned to its automatic mode or removed from the operation. Remote driving of road vehicles has already been demonstrated several times, for example for army vehicles and for maintenance vehicles because of the potentially dangerous situations. In a city environment, the difficulty lies with the environment which might be unpredictable (moving vehicles and/or pedestrians). It is therefore necessary to develop a visualization technique which will allow the remote driver to be well aware of anything which happens around the vehicle and eventually to implement techniques which takes the control of the vehicles in case of potential collision. We must have therefore a combination of human and computer driving which is one of the major difficulties in ADAS (Advanced Drivers Aids Systems). The consortium in well aware of the current developments in this field and some of its members have been active in past or participate in current European Projects such as Save, Protector, Radar-Net, Carsense,….

1.3 Milestones and expected results

The milestones will be the successful demonstration of each of these new or improved systems for the infrastructure which should demonstrate significantly better performances and/or lower cost for the global operation of the systems. The results are the products to be integrated in the infrastructures of future systems.

2. Issues for new technologies for infrastructure

2.1 Fleet management

Since it is expected that a large number of users will have access to a large number of vehicles, it is necessary to develop sophisticated management tools in order to optimize the use of the mobile resources which are not only the vehicles but also the human resources for running smoothly the system (for maintenance, assistance, cleaning,…) and the physical resources such as parking places, recharging stations, etc. Some of this work has already been performed in the Eviac Project but it has now to be put in place and tested operationally. Furthermore, the fact that the vehicles can now be moved autonomously changes the problem by allowing many more "stations" for pick-up or destinations. This will be done by writing specific software in the management system of the fleet for the Inria test site.

Cybercars by definition are under control of a management system in order to adapt the resources to the demand. Such systems have already been developed for car-sharing systems and for industrial AGVs. However, such systems will have to be adapted to the particular problems of public transportation with automated vehicles.

In car sharing systems (CSS) individual users share a fleet of vehicles linked to transit. Planned to ease traffic congestions and to reduce air pollution, CSS programs are being developed in Europe, in Japan and in North America. Among these, systems utilizing electric vehicles (EV) are especially suited for short-range trips and they provide the infrastructure needed for recharging car batteries. Some of their common characteristics include the application of intelligent transport systems (ITS) technologies to support Internet-based scheduling, geographic information systems (GIS), global positioning systems (OPS) and mobile communications for fleet management, and smart PIN-based keys for the cars door lock and ignition. In every case, systems are managed by central control systems (CCS). Socioeconomic appraisals demonstrate the operational cost effectiveness by means of increasing the amount of utilization while limiting the size of the fleet. Some experiments have tackled the difficult problem of redistribution of empty vehicles among the different parking lots but this has been limited by the need for human resources to perform the task.

Most of the work done for the advancement of the automatic guided vehicles (AGV) infrastructure and technology in the previous years was mainly focused on material handling systems (MHS) rather than human transport. For cybernetics transportation systems (CTS), the fleet problems concern essentially the following elements:

- vehicle allocation to a particular demand,
- vehicle relocation after a trip,
- demand management and fare collection,
- distributed versus central management,
- communication architecture.

All of these problems have already been addressed and do not bring any large difficulty except in the optimization (or best compromise) of many design variables.

2.2 Human-machine interface

In simple systems such as the ones already in place, and which have a very limited number of stop points for the vehicles, a system of buttons such as the ones found for elevators is quite easy to understand and simple to put in place. If the system becomes, as expected, much larger, it will not be feasible to install these call buttons everywhere in the city. The most convenient interface will therefore be based on mobile terminals such as mobile phones or PDA and by specific programming on these devices. New digital high speed connections such as GPRS or UMTS will allow for browser-type interfaces on these terminals but one must be careful to use existing guidelines for developing these interfaces. In particular, some form of European propositions for standards will be developed. The interfaces will also be developed inside the vehicles and on fixed terminals with possibly more functions given the comfort of the larger screens. Here again, this represent specific software written for these devices. These interfaces will also have to take into account the need for ticketing which should be developed in a multimodal environment.

2.3 Remote operation

.It is believed that in an automated system, human intervention can still play an important role. In particular with automated vehicles on the road, it may happen that a vehicles is stopped because of a human intervention (emergency switch) or because of a failure of some component, or because of an unexpected obstacle. In all these cases, it is important that a central operator be informed of all the parameters of the situation. In particular, we want to include video communication through the digital network to have a better perception of the situation. We also want the operator to be able to drive the vehicle remotely. Although this has been done in the past for military applications and in laboratory environments, we will develop and test this technique in an urban environment

2.4 Energy management

Here again, we want to take full advantage of the automated driving of the vehicles in order to get them to recharging stations autonomously when this is needed. Automatic docking stations will therefore be built and tested in this Work Package. Results from the Eviac Project are taken into account to develop these stations. Specific research and testing will also be performed in order to measure and optimize the energy consumption of the electric vehicles with respect to the speed control software used in the vehicle.

3. Description of results

3.1 Fleet management (INRIA)

3.1.1 New Software for Fleet management

New software for fleet management of CTS from a central computer using a digital radio network

3.1.1.1 Objective

- To implement and experiment a standard software system for the installation and the operation of cybercars over any network of roads in an efficient way

3.1.1.2 Operational goal

- Develop the design of system architecture for the centralized fleet management software for CTS.
- Develop management rules for the optimisation of the management of user reservation queue, route planning and travel time computation, Real time updating of traffic matrix and redistribution of cybercars after service.
- Develop and implement the management software
- Test and evaluate the performances

3.1.1.3 Baseline reference

- The traffic management systems in Rivium and Praxitele projects.

3.1.1.4 Deliverables

Design tools, Optimisation techniques, Management system, Performance evaluations

3.1.1.5 Description

The centralized fleet management software (CFMS) which has been developed for CyberCar experimental installation at INRIA Rocquencourt caters to the problems of customer allocation, vehicle routing based on real-time awareness of the state of the traffic network and redistribution of empty vehicles after service. The system provides effective decision support through GIS-based infrastructure planning, database management capabilities, dynamic travel time computation and an operator interface for supervision.

3.1.1.5.1 From Infrastructure planning to real-time fleet management

The aim was to build a complete software package integrating off-line infrastructure planning and an on-line real-time fleet management. The external actors involved in the CFMS are: users, vehicles and a human operator. The main functionalities provided by the system are:
Offline

- Infrastructure planning

Online

- Reservation, Scheduling
- Trip and Redistribution Management
- Operator supervision and control
- Data Logging

Each cybercar knows how to get along between adjacent nodes on its own, so the lowest level role of the CFMS in terms of navigation is to indicate the vehicles about the routes to follow which are computed in real-time and are the optimum paths considering the state of the transport network and the associated resources.

A simple message protocol has been developed for communications between the CFMS and the vehicles. Trips are assigned on a free vehicle basis, optimizing user waiting latency (typically less than 5 minutes) as the basic criterion. Special attention has been paid to the field data logging that is used for statistic analysis and optimization in home site locations and fleet sizing.

3.1.1.5.2 System Architecture

The main sections of the CFMS are:

- a GIS
- a DBMS
- a Reservation and Trip Management Module
- an Operator Interface

The spatial data along with the related logistic data is managed with the GIS system and stored in the DBMS, which is itself shared with the core fleet management module. Transport elements are characterized within the DBMS as an extension for geographic data. Its structure is relational type and can be used for both GIS and non-GIS based applications. The DBMS supports small data sets and processes the facility to support external commercial databases to handle large databases.

Elements defining the structure of the network (Nodes and Arc defining a directed graph) are stored as persistent data in the DBMS, while vehicle, client and path are generated and managed dynamically, when system is running online.

3.1.1.5.3 Trip Management

The process of trip management involves four main actions:

- Management of Reservation queue
- Route Planning and Travel Time Computation
- Real time updating of traffic matrix
- Redistribution of vehicles

3.1.1.5.3.1 Management of Reservation queue

The user sends a request to the CFMS telling his user id, origin and destination. The customer requests for the trips are handled by the CFMS on a FCFS (First Come First Served) basis. On receiving a customer request, the customer details are validated. After being found authentic, the customer is allocated a vehicle, a pick-up station and the time at which the pick-up vehicle will reach the user. The customer receives confirmation of his request from the CFMS in 4-6 seconds. Customers can also send queries and requests concerning the modification and cancellation of the trips.

3.1.1.5.3.2 Route Planning and Travel Time Computation

Route planning is the process that helps vehicles to secure a route prior to driving a specific part of their journey. The vehicles know how to displace between the adjacent nodes but not about the next nodes. It is the fleet management system who assigns the routes.

The network data for the optimum route computation is derived from the DBMS unit as input. The fastest path is computed by the CFMS as a function of the cost of travelling on the link using Dijkstra's algorithm. The shortest trip for the customer is ensured by the updated arc travel times of the network. Since the test network employed for CTS routing is static, the travel cost remains constant for a trip. In dynamic networks, the travel cost is time dependent and randomly varying.

The main objective of the CFMS is to send the customers to their destinations in minimum time. The trip travel time is obtained from the travel times of the constituent arcs of the path. The arc travel time primarily depends on the length, gradient and speed of vehicles on the arc.

Let us consider a single arc a with origin *i* and destination *j*. The length of the arc is l_{ij} and the speed of the moving vehicles on the arc is represented by v. The arc travel time or the arc weight is denoted by W_a. The impedance (in sec per 100m) of the arc is represented by I_{ij} and the time to clear the obstacles (if any on the arc) is O_{ij}. The arc weight W_a is given by:

$$W_a = l_{ij} / v + l_{ij} * I_{ij} + \sum O_{ij}$$

To compute the trip travel time T_{trip}, the arc weights for the optimum path provided by the CFMS are summed up i.e.

$$T_{trip} = \sum_{a=1}^{p} W_a$$

where *p* represents the total number of links comprising the path.

3.1.1.5.3.3 Real time updating of traffic matrix

The traffic matrix presents a real time picture of the dynamic routing of vehicles on the network. The main fields of the matrix are vehicle id, vehicle origin, vehicle destination, vehicle status and the path assigned.

The data required from the vehicle are its absolute position and the arc which it is occupying. The data sent to the vehicle is the sequence of the arcs to the destination and the user id for the trip.

3.1.1.5.3.4 Redistribution of vehicles

On completion of the customer's trip, the vehicle is ready for reallocation to a new customer request. If there is no pending customer request, the vehicle status is set to free and is sent for parking to the nearest parking station.

Presently, the centralized fleet management software has been developed for testing the certain and known user demands on static networks. A next step of the work concerns the enhancing of the capacities of the fleet management software to deal with uncertain customer demands for dynamic networks.

3.1.2 Software development of the fleet management (FROG))

3.1.2.1 Objective

- To develop a software system for efficient fleet operation over a networked track maintaining block safety

3.1.2.2 Operational goal

- Develop traffic management rules
  - To optimise the transport capacity of the CTS.
  - For different levels of transport demand
- Develop a vehicle zone and path assignment system that meets future certification requirements.
- Engineer & test such a system

3.1.2.3 Baseline reference

- The traffic management system in Rivium Pilot project

3.1.2.4 Deliverables

- New traffic management system embedded in a Fleet management system

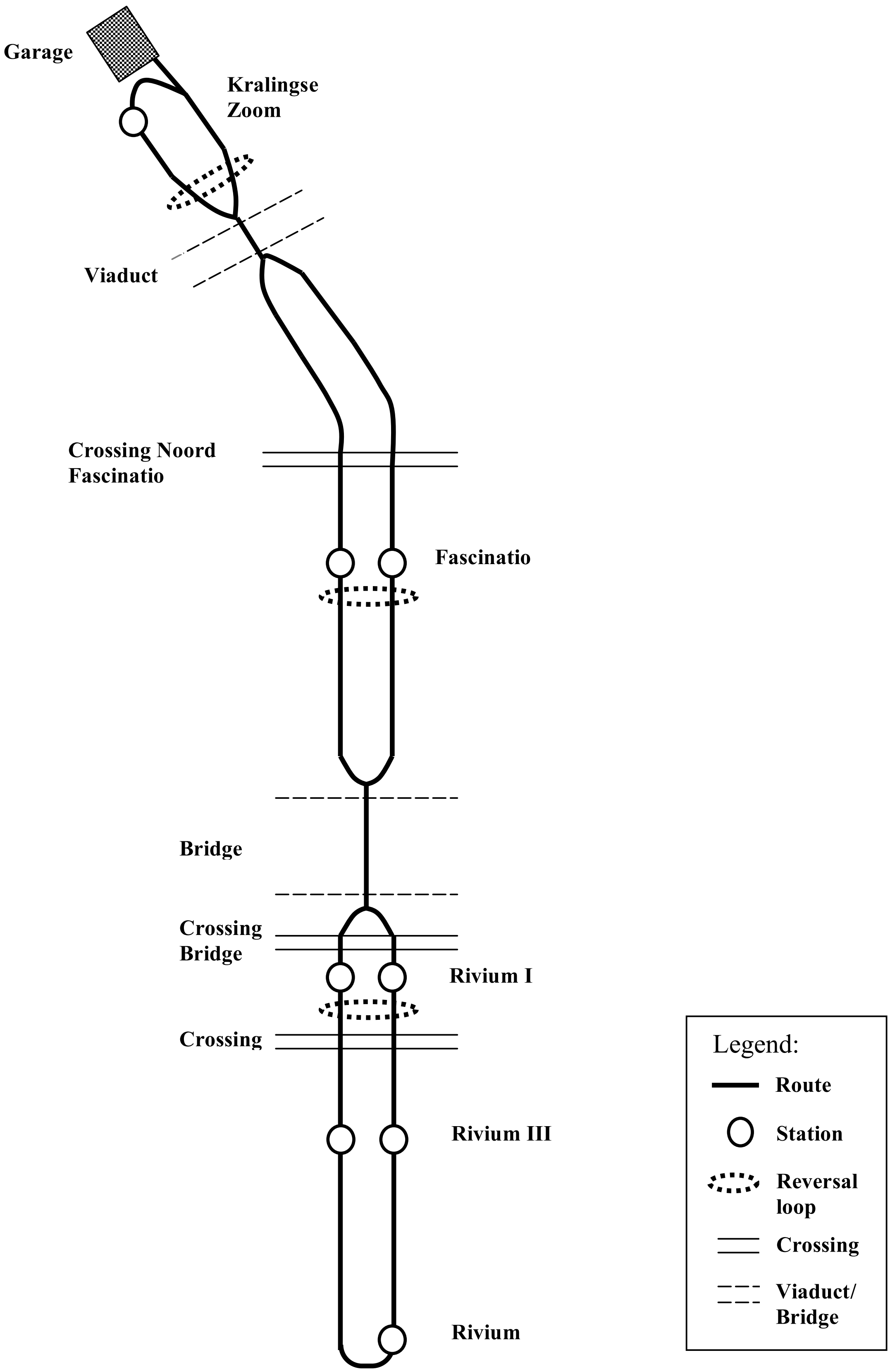
3.1.2.5 Description

A description of the requirements is given. With the requirements a system has been implemented. The implementation will be used for the Rivium Case. The requirements have been discussed with the customer.
The implementation is tested in a simulation-environment. The simulation-environment is improved with possibilities to visualize the different scenario's. Also the different scenario's can be changed anytime. With the simulation the throughput of the system can be tested. The results will be used to optimize the system.
On the Rivium-site the implementation will be tested and will be compared with the simulated results.
The description gives an overview of the route (course) with a detail description of the different sectors of the route. This zone will be used to ensure the safety of the route. From the fleet-management system the zone will be released for a particularly vehicle.
In the description are also the pre-conditions given for the route or for particularly parts of the course.
The total scenarios of a day are described.

The scenarios are implemented in the existing SuperFROG application. SuperFROG is an application which is used in a industrial environment to control a fleet of Automatic Guided Vehicle's (AGV's). The program is optimized to transport goods in a factory in the most economic way. For the transport of people with CTS the program will be changed according the requirements and the description of the scenarios.

3.1.2.5.1 Course

A principle lay-out is out-lined as follows:



3.1.2.5.2 Layout Overview

The RIVIUM layout can be split up into a number of different sections. Presented below is a detailed description of each layout section:

Each layout section is either single or double lane and a section can be of several different types. The length and a maximum speed (the maximum speed is usually determined by the width of the route in a particular section) are also specified for each section. Based upon a maximum speed and the length, the time needed to travel a certain section can be calculated. The time needed to travel a certain section is calculated by dividing the length of a particular section by the maximum speed in that section. The time needed to travel a certain section also depends on the acceleration/deceleration characteristics of a vehicle. This acceleration/deceleration is taken into account by the time needed.
A vehicle can stop at sub stations and at main stations. While the "Time needed" column contains the times needed by the vehicle to travel a certain section the "Must stop" column contains the additional times the vehicle needs to stop at a certain station. The time that is lost by stopping at a (main or sub) station depends on the time it takes to slow down from 6 m/s to 0 m/s, the time to open the doors, the minimum time the doors need to be open, the time to close the doors and the time it takes to accelerate from 0 m/s to 6 m/s.

3.1.2.5.3 Prerequisites

Requirements

The next three sections will feature overviews of different requirements. Each requirement will have a priority. A low number designates a high priority. A requirement of priority 1 means that this requirement is a hard requirement, such a requirement has to be met.

General requirements

This section features general requirements. These requirements will have to be met in all scenarios.

No	Requirement	Remarks	Prio
1	A vehicle has to stop at a station whenever a person wants to get either on or off the vehicle.		1
2	A vehicle must be able to drive from "Station Kralingse Zoom" to "Station Rivium IV" in 6 minutes	This is without having a stop and without taking weather restrictions into account.	1
3	Between two successive closings crossings should be open for other traffic for at least 10 seconds.	The crossings involved are situated in the "Crossing Fascinatio" section, the "Crossing bridge" section and the "Crossing Rivium I" section.	1
4	Single lane sections will have to be synchronized.		1
5	All vehicles must have enough battery charge to ensure the completion of all scenarios.	This is why vehicles are assigned to different groups. When one group is active the other group will be able to charge	1
6	Vehicles that have to stop because of synchronization issues will wait at stations.	This can cause a vehicle to make an extra stop at a station nobody requested to stop at.	2
7	Synchronize at sections containing crossings. This means that two vehicles will try to cross a crossing simultaneously.	The crossings involved are situated in the "Crossing Fascinatio" section, the "Crossing bridge" section and the "Crossing Rivium I" section.	2

On demand requirements

This section features on demand driving requirements. These requirements will have to be met while executing on demand scenarios.

No	Requirement	Remarks	Prio
1	Vehicles have to spread as evenly as possible throughout the area.	Vehicles will only spread throughout the area when they have finished their actions.	1
2	An empty vehicle gives way to vehicles having passengers on board.		2

Time table requirements

This section features timetable driving requirements. These requirements will have to be met while executing timetable scenarios.

No	Requirement	Remarks	Prio
1	Three to six vehicles are active.		1
2	Each vehicle drives four laps per hour.	This means that when there are six vehicles	1

		active, every station will be passed by a vehicle every 2.5 minutes.	
3	Vehicles that are not driving in the rush direction have to give way to vehicles driving in the rush direction.		1
4	Vehicles driving in rush direction will only stop at a station when they receive a signal to do so.		1

3.1.2.5.4 Scenario Overview

The following scenarios will occur during a normal day:

Schedule	**start**	**finish**	**duration**	**loops/hrs**	**Vehicles**	**Operational**	**Charging**
On demand early morning	6:00	7:30	1:30	2.5	3	Group A	Group B
Morning rush	7:30	9:30	2:00	4	4-6	Groups A+B	-
On demand morning	9:30	12:00	2:30	2.5	3	Group B	Group A
On demand afternoon	12:00	15:30	3:30	2.5	3	Group A	Group B
Evening rush	15:30	18:00	2:30	4	4-6	Groups A+B	-
On demand evening	18:00	21:30	3:30	2.5	3	Group B	Group A
Operational stop	21:30	6:00	8:30	-	6	-	Both

Each vehicle is assigned to either group A or group B. The different scenarios can be divided into two main categories: On Demand scenarios and Time Table scenarios. Both scenarios are described (from a passenger's point of view) in a latter chapter.

Critical areas and critical points

All of the sections described in paragraph 1.2 have either one lane or two lane roads. When a section contains only a one-lane road, vehicles coming from different directions cannot enter that section simultaneously. This means that one vehicle has to give way to another vehicle. During rush hours vehicles, which are not driving in the rush, direction will have to give way to vehicles driving in the rush direction. A critical area is a section that requires some extra traffic control. A section containing a one-lane road is an example of a critical area. Such critical areas usually contain either a bridge or a viaduct. Another example of a critical area is a section containing a crossing. Such a section is also a critical area because vehicles coming from different directions will either have to enter such a section simultaneously or the gap between the entrance of each vehicle has to be as large as possible.
Each critical area is preceded by a critical point. When a vehicle is driving in rush direction critical points are ignored. When a vehicle is not driving in rush direction and it encounters a critical point SuperFROG decides whether the vehicle must stop or move on. Such a decision is based upon certain criteria. A critical point is usually situated just before a station. Below is a list of all critical areas, the station connected to each critical area and the period during which the critical area / station connection is valid. Note that each critical area appears twice in the list below because the rush direction during morning rush differs from the rush direction during evening rush. Also note that all critical areas are active during on demand driving.

Critical area	**Station (critical point)**	**Active**
Viaduct	Kralingse Zoom	Evening rush, on demand scenarios
Viaduct	Fascinatio	Morning rush, on demand scenarios
Crossing Fascinatio	Kralingse Zoom	Evening rush, on demand scenarios
Crossing Fascinatio	Fascinatio	Morning rush, on demand scenarios
Brug	Fascinatio	Evening rush, on demand scenarios
Brug	Rivium I	Morning rush, on demand scenarios
Crossing brug	Fascinatio	Evening rush, on demand scenarios

Crossing brug	Rivium I	Morning rush, on demand scenarios
Crossing Rivium I	Rivium I	Evening rush, on demand scenarios
Crossing Rivium I	Rivium III	Morning rush, on demand scenarios

On Demand scenarios

An on demand scenario is a scenario in which vehicles are strategically placed throughout the entire site. Such a strategically distribution of vehicles is accomplished by a distribution order; see [2]). Such a distribution order will take the time of day into account. During the morning people are expected to travel mostly from "Station Kralingse Zoom" to "Station Rivium IV". This means that in the morning a distribution order will cause most vehicles to be strategically placed along this route. In the evening and afternoon the distribution order will cause most vehicles to be strategically placed along the route coming from "Station Rivium IV" and going to "Station Kralingse Zoom".
Vehicles will only start moving when SuperFROG has received a request from a station to pickup one or more passengers. SuperFROG will use an algorithm to determine the most efficient way to handle all requests. This algorithm will have the following guidelines:
Only one vehicle will drive to a station when one or more request is/are originated from this station.
A vehicle will only stop for other passengers when this is possible without making a detour (this is valid for an empty vehicle as well for a vehicle transporting passengers).
A request preferably will be assigned to a busy vehicle (of course taking the guideline above into account).
A vehicle will use a reversal loop whenever this results in a shorter total driving distance.
A passenger has to give the stop request before the vehicle has driven past the critical point of the substation the passenger wants the vehicle to stop at (a vehicle will always stop at a main station).
When several vehicles are driving simultaneously the critical points will play a major role in the propagation of vehicles. Sometimes vehicles will have to wait for another vehicle at the critical areas. Which vehicle gives way to another vehicle depends on the status of the vehicles involved (a vehicle is considered empty when no destination is chosen from within the vehicle).
Both vehicles are empty. The vehicle that reached the critical area last will have to wait until the other vehicle has travelled the critical area.
One vehicle is empty while the other vehicle is not. The vehicle that is empty will have to wait until the other vehicle has travelled the critical area.
Both vehicles transport passengers. The vehicle that reached the critical area last will have to wait until the other vehicle has travelled the critical area.
Whenever all vehicles are idle (all requests have been handled) a distribution order will be issued.

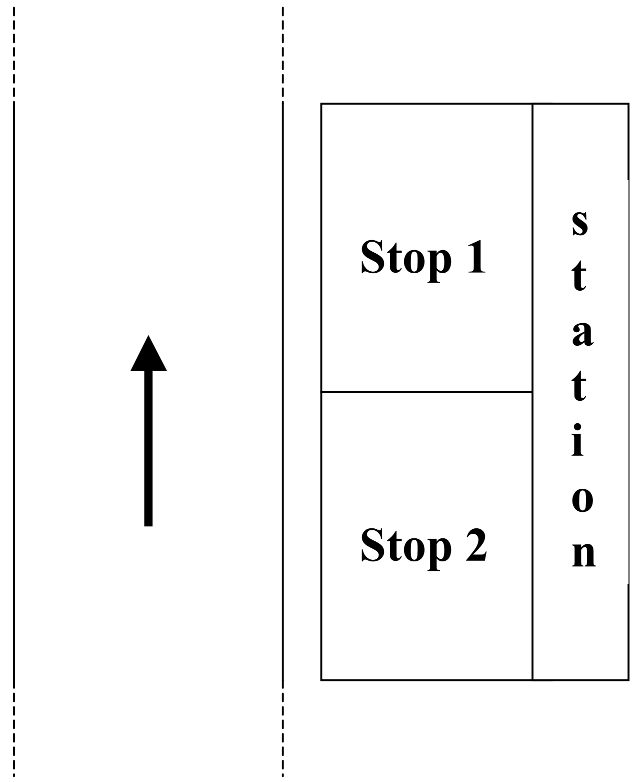
3.1.2.5.4.1 Time Table scenarios

A Time Table scenario is a scenario in which vehicles will start driving a loop from main station to end station and back to main station again at fixed intervals. During the morning rush commuters travel mostly from "Station Kralingse Zoom" in the "Station Rivium IV" direction. Therefore "Station Kralingse Zoom" will be the main station and "Station Rivium IV" will be the end station during morning rush. During the evening rush commuters travel mostly the opposite way. Therefore "Station Rivium IV" will be the main station and "Station Kralingse Zoom" will be the end station during evening rush.
During rush hours four to six vehicles will each drive four laps per hour. This means that a vehicle will start from main station every 2.5 minutes (when driving with 6 vehicles), every 3 minutes (when driving with 5 vehicles), every 3.75 minutes (when driving with 4 vehicles) or every 5 minutes (when driving with 3 vehicles).

The journey from main station to end station is always the rush direction. Vehicles driving in rush direction will always try to travel the journey from main station to end station as fast as possible. This means that vehicles driving in rush direction will only stop at a station when they receive a signal (either from a passenger inside a vehicle or from someone waiting at a station) to do so. When a vehicle arrives at the end station it waits for a fixed amount of time and starts the journey from end station to main station (thus travelling in non-rush direction). A vehicle will compensate for the time it has won while driving in the rush direction (because it did not stop at all stations) by waiting longer at the end station. When a vehicle is driving from end to main station, the decision points situated just before the three sub stations become active and a decision to either stop at a certain station or continue without stopping at a certain station is made. The above-described behaviour will ensure vehicles to start from the main as well as the end station at fixed times.
Because vehicles will not always stop at a station, the arrival times at stations can fluctuate. To ensure accurate estimated time of arrival at stations, the estimated time of arrival will initially be based upon a worst case scenario. This means that the estimate is based on the assumption that the vehicle has to stop at each sub station. Whenever a vehicle did not stop at a certain station a new estimated time of arrival is made and displayed at each station still to be visited. This means the vehicle will arrive sooner than was displayed before at those stations.
Morning rush and evening rush will start at predefined times. The operator will have the ability to change the active scenario, start and stop time of the scenario's, the rush direction and the number of vehicles in operation.

3.1.2.5.4.2 Station Scenario

It is assumed that each station has two stop positions. A vehicle that arrives at a station usually stops at the stop 1 (see figure below) to allow passengers first to get off the vehicle and then allow other passengers to enter the vehicle. When a vehicle arrives at a station and a vehicle is already parked at the stop 1 (this usually only happens at "Station Kralingse Zoom" and "Station Rivium IV") it will park at the stop 2 to allow passengers to leave the vehicle (a message on the vehicle will tell people not to enter the vehicle). As soon as the first vehicle has left stop 1 the second vehicle will move to this position and allow passengers to enter the vehicle.



3.1.2.5.5 Scenarios

This chapter describes all possible scenarios to provide the reader with some insight in the workings and limitations for each scenario. Each section below describes a particular scenario in detail. The assumed active number of vehicles in both Time table scenarios will be six. Please be aware that each description is a theoretical description of a scenario without taking external influences into account and assuming the vehicle is driving ideally. These descriptions will surely be subjected to changes after testing.

3.1.2.5.5.1 Early morning

Upon activation of the system three vehicles will automatically leave the garage in a row. Because it is assumed that all passengers will leave from "Station Kralingse Zoom" all vehicles will be positioned at "Station Kralingse Zoom" (two vehicles will be positioned at the station and one vehicle will be positioned at a parking place in the vicinity of the station).
When a destination is chosen from within a vehicle this vehicle will wait x-time to allow other passengers to also enter the vehicle. This waiting time at "Station Kralingse Zoom" will be longer because more passengers can be expected here. Due to the minimal opening time the crossing at Fascinatio should be open, the next vehicle will not leave within 33 seconds [4].
When the vehicles have transported one or more passengers the vehicles will be mainly strategically placed along the route from "Station Kralingse Zoom" to "Station Rivium IV" (typically two vehicles at "Station Kralingse Zoom" and one vehicle somewhere between "Station Kralingse Zoom" and "Station Fascinatio").
During the rest of the early morning scenario SuperFROG will send a vehicle to a station as soon as somebody originated a request from this station. The person will go into the vehicle and enter a destination. After a specified period of time the vehicle will drive to the given destination (maybe stopping to allow other persons to get in or off the vehicle along the route) and allow the passenger to get off the vehicle.

3.1.2.5.5.2 Morning Rush

When the system changes from "Early morning" scenario to the "Morning rush" scenario the three active vehicles will all drive to "Station Kralingse Zoom". One by one the vehicles will leave this station to start driving their laps. Meanwhile the three vehicles that were still in the garage will also drive to "Station Kralingse Zoom" to start driving their laps. Vehicles will start driving laps at fixed intervals.
A vehicle leaves from "Station Kralingse Zoom" and tries to drive as fast as possible (taking into account the maximum speed of each section) to "Station Rivium IV". The vehicle will only stop at a station when it receives a request to do so. When the vehicle has arrived at "Station Rivium IV" it will wait for a number of seconds to allow passengers to leave and enter. This waiting time will be increased with 26 seconds for each station the vehicle did not stop at.
During the return journey the vehicle will stop at stations for synchronization of critical areas. Below the main dependencies are mentioned where the stops are based on.
The first decision point the vehicle encounters is the one situated just before "Station Rivium III". The vehicle will never stop here unless:
it received a request to stop
the vehicle that approaches the critical area ("Crossing Rivium I") has not stopped at "Station Fascinatio" and "Station Rivium I"

The second decision point the vehicle approaches is the one situated just before "Station Rivium I". The vehicle will never stop here unless:
it received a request to stop
it has not stopped at "Station Rivium III" and the vehicle that approaches the critical areas ("Crossing bridge" and "Bridge") has stopped at "Station Fascinatio"
It should be noted that it is not always possible to optimally synchronize at "Crossing Rivium I" and "Crossing bridge" because of the characteristics of the entire route.
Finally the vehicle approaches the third critical point ("Crossing Fascinatio" and "Viaduct"). The vehicle will never stop here unless:
it received a request to stop
it has stopped at either "Station Rivium III" or "Station Rivium I"
The vehicle will have to stop a number of seconds longer than the usual 10 seconds only when:
it has stopped at both "Station Rivium III" and "Station Rivium I"
Some time after passing the last critical area the vehicle will arrive at the main station again. Passengers will first be able to leave the vehicle after which the vehicle will have to wait for a certain amount of time (depending on the number of stops it made) before a new lap can start again.

3.1.2.5.5.3 Morning

This scenario will be essentially the same as the early morning scenario but now the strategically placing of vehicles along the route from "Station Kralingse Zoom" to "Station Rivium IV" is slightly different (typically one vehicle at "Station Kralingse Zoom", one vehicle somewhere between "Station Kralingse Zoom" and "Station Fascinatio" and one vehicle at the reversal loop at "Station Rivium I").
During the transition from the "Morning rush" scenario to this scenario the three vehicles having the lowest battery capacity will be sent to the chargers. The vehicle will display the "Garage" destination. If passengers are on board of the vehicle they will be first dropped at their destination. The vehicle will request all passengers to leave the vehicle before it will be send to the chargers.

3.1.2.5.5.4 Afternoon

The three vehicles that were charging during the "Morning" scenario will now be used while the other three vehicles will be sent to the charger. As already explained the vehicles will be mainly strategically placed along the route from "Station Rivium IV" to "Station Kralingse Zoom" (typically one vehicle at "Station Rivium IV", one vehicle at the reversal loop at "Station Rivium I" and one vehicle somewhere between "Station Rivium I" and "Station Fascinatio"). When somebody requests a vehicle SuperFROG sends a vehicle to the station the request originated from (by using the algorithm). The person will go into the vehicle and enter a destination. After a specified period of time the vehicle will drive to the given destination (maybe stopping to allow other persons to get in or off the vehicle along the route) and allow the passenger to get off the vehicle.

3.1.2.5.5.5 Evening Rush

When the system changes from "Afternoon" scenario to the "Evening rush" scenario the three active vehicles will all drive to "Station Rivium IV". One by one the vehicles will leave this station to start driving their laps. Meanwhile the three vehicles that were still in the garage will also drive to "Station Rivium IV" to start driving their laps. Vehicles will start driving laps at fixed intervals.
The vehicle leaves from "Station Rivium IV" and tries to drive as fast as possible (again taking into account the maximum speed of each section) to "Station Rivium IV". The vehicle will only stop at a

station when it receives a request to do so. When the vehicle has arrived at "Station Kralingse Zoom" it will wait for 2 minutes to allow passengers to leave or enter. This waiting time will be increased with 26 seconds for each station the vehicle did not stop at.

During the return journey the vehicle will stop at stations for synchronization of critical areas. Below the main dependencies are mentioned where the stops are based on.

The first decision point the vehicle encounters is the one situated just before "Station Fascinatio" (Actually "Station Kralingse Zoom" is the first decision point but the only criteria for both critical areas ("Viaduct" and "Crossing Fascinatio") is the moment of departure from the critical point). The vehicle will never stop here unless:

it received a request to stop

the vehicle that approaches the critical areas ("Crossing brug" and "Bridge") has not stopped at "Station Rivium III" nor at "Station Rivium I"

The second decision point the vehicle encounters is the one situated just before "Station Rivium I". The vehicle will never here stop unless:

it received a request to stop

it has not stopped at "Station Fascinatio" and the vehicle approaching the critical area ("Crossing Rivium I") has not stopped at "Station Rivium III"

it has stopped at "Station Fascinatio" and the vehicle approaching the critical area has stopped at "Station Rivium III"

This time it is not always possible to optimally synchronize at all crossings. This is also due to the characteristics of the entire route.

Some time after passing the last critical area the vehicle will arrive at the main station again. Passengers will first be able to leave the vehicle after which the vehicle will have to wait for a certain amount of time (depending on the number of stops it made) before a new lap can start again.

3.1.2.5.5.6 Evening

This scenario will essentially be the same as the afternoon scenario but now the strategically placing of vehicles along the route from "Station Rivium IV" to "Station Kralingse Zoom" is slightly different (typically two vehicles at "Station Rivium IV" and one vehicle somewhere between "Station Kralingse Rivium I" and "Station Fascinatio"). During the transition from the "Evening rush" scenario to this scenario the three vehicles having the lowest battery capacity will be sent to the chargers. If passengers are on board of the vehicle they will be first dropped at their destination. The vehicle will request all passengers to leave the vehicle before it will be send to the chargers

3.1.2.5.5.7 End of day

All vehicles will be sent to "Station Kralingse Zoom" while delivering passengers at their destinations after which the vehicles will drive one by one to the garage where they all will charged.

3.1.2.5.6 Conclusions

The customer has the possibilities to use different scenarios depending on the amount of traffic. The scenarios are optimized for the different demands of the passengers.

3.1.3 Infrastructure control system (RUF)

RUF will work on improvements of the infrastructure control system required to make sure that vehicles do not collide when they are guided through the junction.

3.1.3.1 Objective

- To develop a RUF network simulator to demonstrate how a junction in the network can handle the flow of crossing vehicles.

3.1.3.2 Operational goal

- To develop a new software (Delphi programming tool) to run on a PC.
- To be able to adjust relevant parameters such as flow distribution (straight, right, left and off) to evaluate the impact on capacity of the junction.
- To test various configurations of junctions in order to optimise its function.

3.1.3.3 Baseline reference

- Nothing similar exists

3.1.3.4 Deliverables

- Two versions of simulators. One for a junction and one for the line between junctions.

3.1.3.5 Description

RUF is a 2nd generation CyberCar which uses the cybercar qualities in the transition between manual mode and automated mode.

Illustration

Fleet management in this context is a question about the relevant control system for the automated mode using a network of guideways covering a large area. The management of the fleet of individually owned vehicles driving automatically through the network is an important task not yet solved in other systems.

The typical trip with a ruf (the car size vehicle of the RUF system) could be:

- The driver starts from his home in the morning. The ruf starts silently since it is an electric car. There are no cold start emissions since an electric motor needs no warm up period. He drives a few kilometers along the normal roads and control the vehicle manually. He tells the ruf computer where he wants to go so it is ready to deliver the information to the system.
- When the ruf comes close to the access rail, the system reads the destination data and guides the ruf to the access rail at a speed of 30 km/h. The destination data is used to allocate the shortest route through the network to the ruf.
- The supervisory system calculates if the shortest route will cause any of the sections to become overloaded. If that is the case, the ruf will get another route which is a little longer than the shortest.

- Once the route has been decided, the control of the rufs is handled by the junctions individually. When one junction (Jp) sends a flow of rufs in the direction of another junction (Jq) the rufs are controlled by Jq. It takes care of the train creation process as well as the acceleration and deceleration of the train on the line between the two junctions.
- The ruf will now be guided to the access rail at 30 km/h and change from driving on the road to "riding" on the monorail. A test is performed in order to make sure that all functions are OK so it can be allowed access to the main line. If not, it will be rejected and will have to continue via the road network until the error has been corrected.
- The accepted ruf is now automatically driven through the network with a top speed of 150 km/h and a speed of 30 km/h through every junction. In a typical network with 5 km between junctions, this will correspond to approx. 120 km/h on average. A typical speed from door to door will be around 80 km/h. Since the vehicle flow is system controlled, the travel time on the network will be predictable.
- When the ruf approach the exit, the passenger is asked if he is ready to take over. If he doesn't react, the system assumes that he has fallen asleep and he is then automatically guided to a stop at a parking place near the exit. The system will then try to wake him up or call for help if needed. He will have to pay a significant amount of money for this service in order to limit the number of parked rufs.
- At the exit it is also tested if it is possible to continue via the road system. If there is congestion at the egress ramp, the ruf will be redirected to the second best exit and will have to go back via the road network. Every junction can have multiple exits in order to minimize this problem. It is also wise to plan the exits so that they are placed in parts of the street network where there is enough capacity. A RUF network should be complementary to the highway network.

In order to manage the flow of vehicles through the network, a control system is needed. The scope of this work is to create a PC based simulation of this control system.

Background

With the control philosophy used in the RUF system, it is possible to make a network scalable without problems. This means that a system can have any size without getting problems with computer power.

The control software of a real system will consist of 3 layers:

1) A supervisory control system takes care of the dynamic route planning so that the flow on any section of the network can't exceed its capacity. If capacity problems arise, some trips will be redirected to follow less ideal routes (see fig. 3).
2) A line control system takes care of the train creation process. The length of trains will depend on the actual flow of vehicles (see fig. 4). In this simulator version it is assumed that all trains are dissolved before reaching the junction, so that the rufs arrive one at a time with a 1 second headway.
3) A junction control system (as shown in rufsim.exe) takes care of access/egress, including control of vehicle speeds, directional changes and the merging of vehicles from different directions (see fig.5).

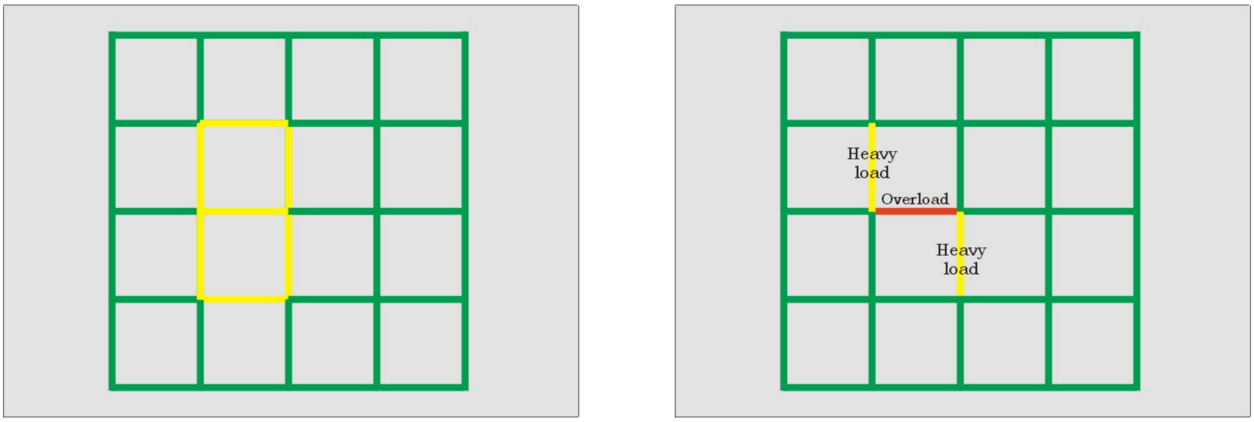


Fig. 3. Redirection in case of potential overload. The figure to the left shows what can happen if every ruf is allowed the shortest possible route. Since one section will be overloaded, the supervisory system will choose alternative routes for some of the rufs. This will mean that more sections are heavy loaded, but no overload appears (right).

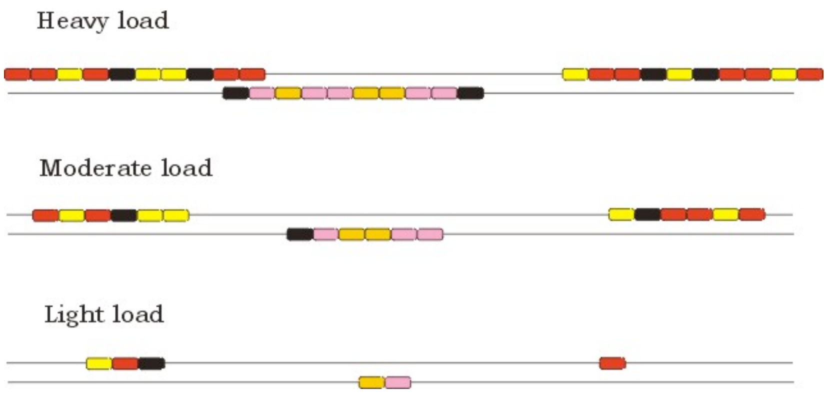
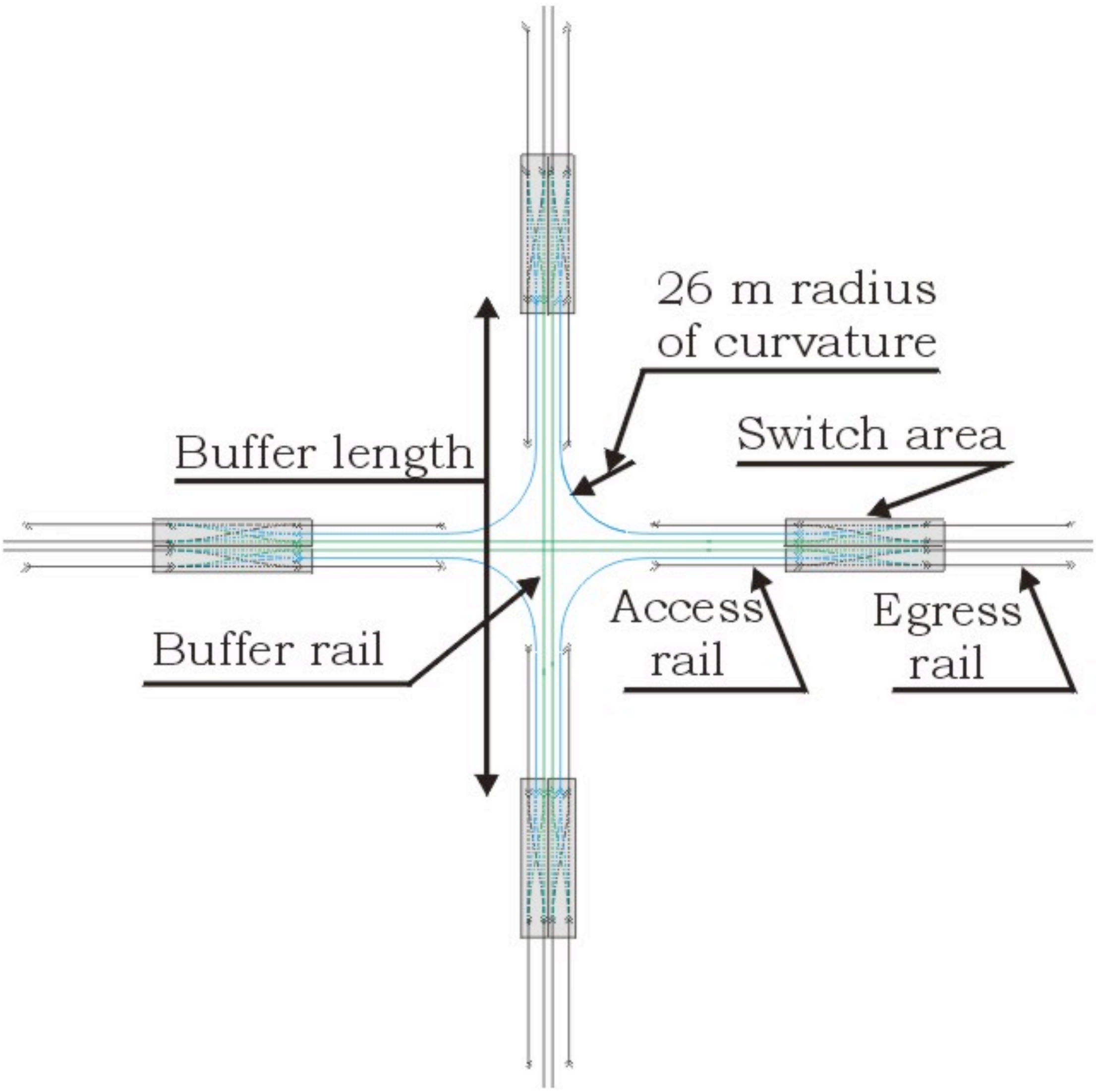


Fig. 4. Train formation

Fig. 5. Junction layout without left turn



The theoretical capacity of a junction is 1 ruf per second or 3,600 rufs per hour per direction. This means that the junction has potential to handle 4 x 3,600 rufs per hour.

For this simulation, the junction has been designed to allow the rufs to only enter, pass straight through the junction, turn right or leave the rail system. This junction design is much simpler than a junction design where left turns are allowed and it is still possible to get from any Origin to any Destination in the area covered by a typical grid network with minimal route deviations for only a few vehicles.

It is obvious that the distribution of rufs arriving at a junction can be composed in such a way that it would be impossible to handle the flow. If for example 60% of the maximum capacity from one direction needs to merge with 50% of the maximum capacity from another direction, the merged flow would equal 110% of capacity. In this case, some of the rufs would have to be redirected to an alternative route or required to leave the system.

In a typical grid-type network (5 x 5 km grid) and with typical commuter trips of 20 km, a typical trip will make use of 3 sections of the network and pass through 4 junctions. Most of the rufs using the network will be driving more than 20 km, since the ones making trips of less than 5 km will probably not use the system. This means that a reasonable distribution of arriving rufs could be 40% going straight ahead, 30% turning right, 20% leaving the system and that total flow would be 10% less than full capacity (i.e. 10% of the spaces would be empty, on the average).

The control philosophy used for this simulation is the following:

- Entering the system is restricted. Only when the flow away from the junction is lower than the capacity, access is allowed.
- A test of mechanical functions is performed at the access rail and defective vehicles are forced to leave at the egress rail following immediately after the access rail. This function is not shown in this version of the simulator.
- The rufs using a right turn will run at constant speed (8 m/sec) all the time. The radius of curvature is more than 26 m so passengers will feel comfortable during these turns.
- A ruf that wishes to leave the system will do so at the first possible exit (unless there is unacceptable congestion at the street level at that exit).

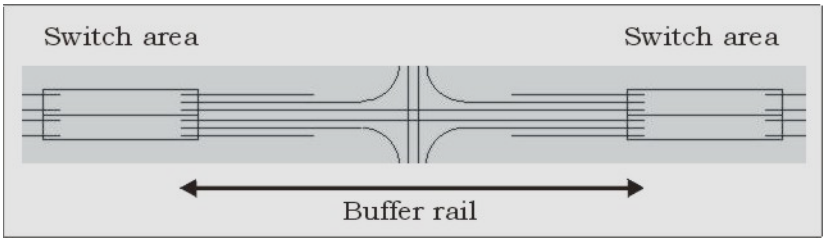


Fig. 6. Buffer rail

- The 4 switch areas are separated by grade separated buffer rails where ruf speed can be raised up to an upper limit or lowered in order to delay the rufs.

- The speed on the buffer rails must not get below 4 m/sec in the worst case with 2 uncoupled rufs with minimum spacing (8 m at the beginning of the buffer rail). In this case the separation would go down to 0.5 m. This problem will show on screen as a cluster of rufs in the middle of the buffer rail. In the coming versions, some of the rufs will be forced to change route (wave-off) in order to solve the conflict.

- The acceleration and deceleration rate is kept within appropriate comfort limits (jerk less than 2 m/sek^3 and acceleration/deceleration less than 2 m/sec^2) along the buffer rail.

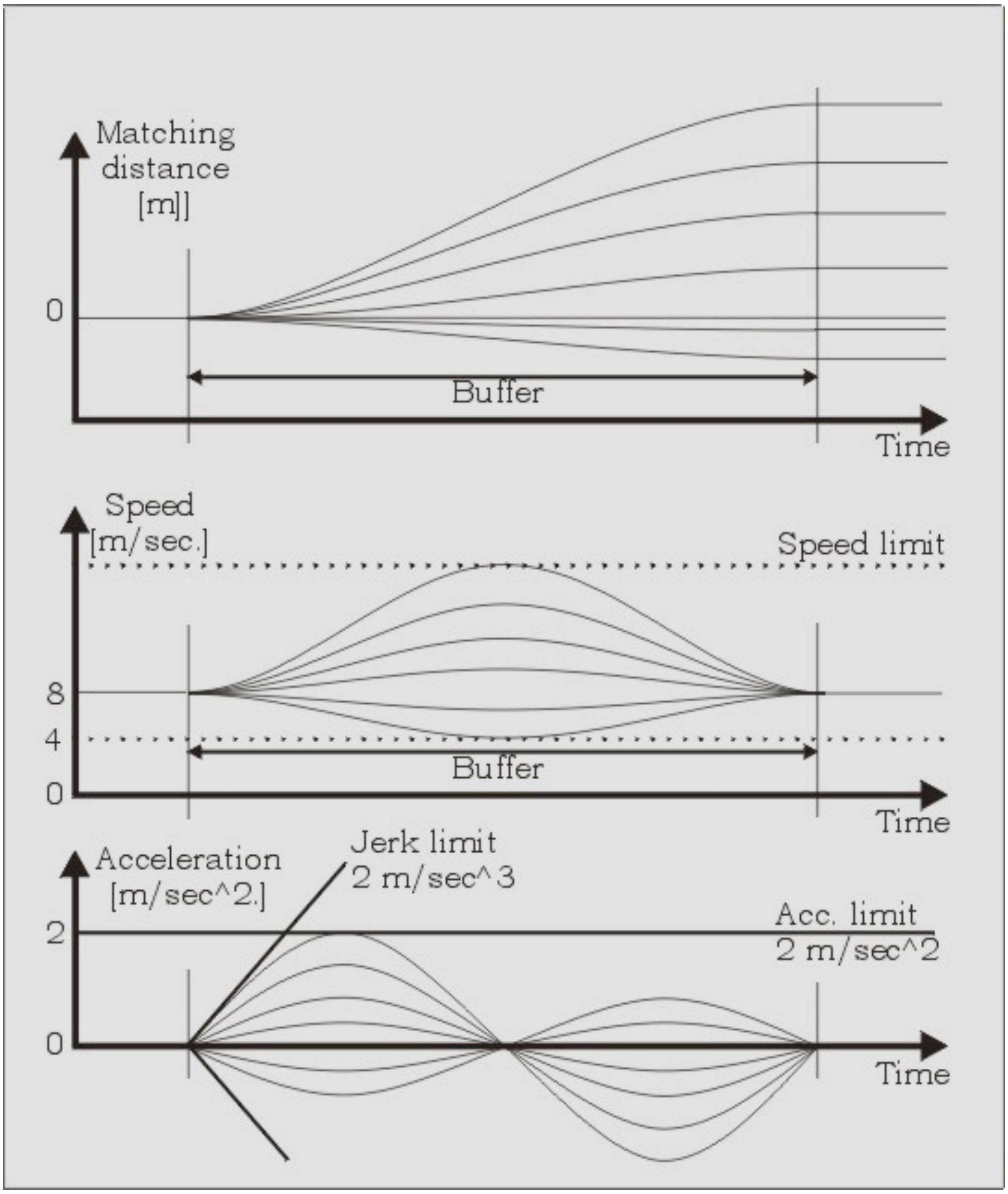


Fig. 7. Kinematic curves on the buffer rail.

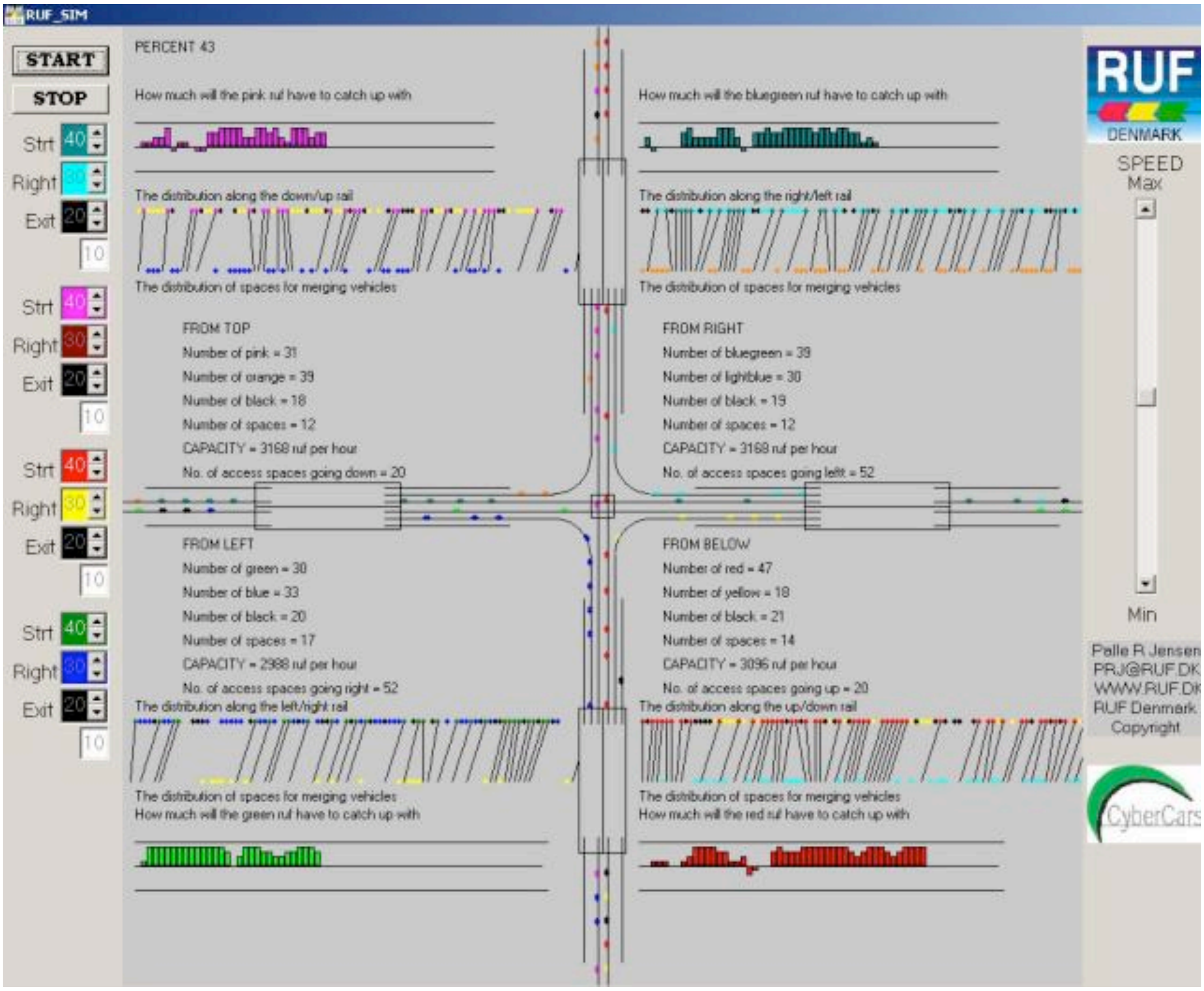
The desired matching distance is obtained by using the corresponding speed curve which has to respect the acceleration and jerk limitations.

The program will try to find open slots in the flow so that turning rufs can merge smoothly into the flow of through vehicles. A through ruf will try to accelerate as much as possible to catch up with an open slot, but if there is no open slot available to permit a merge, the program will slow it down and look further down the line for an open slot to merge into.

If no open slots are available, the simulator may slow down the rufs on the buffer rail, but if at some point the density of rufs will becomes too large, one or more will have to leave the system or to change direction (this "wave-off" action is not shown in this version of the simulator).

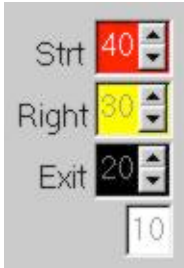
The overall supervisory system (not included in this version of the simulator) will know if one section is becoming overloaded as soon as a request is made from a ruf wanting to enter the network. The supervisory system might decide that the ruf must take another route in order to avoid problems. This is not a big problem since a network would provide several possible routes from a given Origin to a given Destination.

Program interface:



Clicking on the START button will create a random distribution of rufs and send 100 of them across the screen from all 4 directions during a 100 second time period.

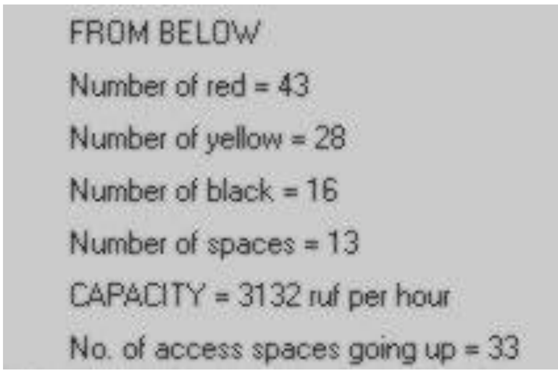
From LEFT: Green are straight, Blue are turning right, Black are leaving
From BOTTOM: Red are straight, Yellow are turning right, Black are leaving
From RIGHT BlueGreen are straight, LightBlue are turning right, Black are leaving
From TOP: Pink are straight, Orange are turning right, Black are leaving



The four spinners can be used to change the directional distribution before starting the simulation. They are linked so that you can only start at the top and change the upper spinner (40). The other two will change proportionally. Once you change the top, can you then change the 2nd and when you have done this, you can change the 3rd values. The number in the box at the

The overall speed can be set with the scrollbar and it is preset to allow one vehicle to enter from each direction every second on fast computers (> 500 MHz). On slow computers it will not be possible to increase speed and it may not even be possible to run at 1 ruf per second.

When the simulator stops, the actual capacity based upon the 100 randomly distributed rufs can be seen on screen. It is also possible to see how many rufs could have had access to the system if they were ready



and waiting at the access rail.

The simulation has been run satisfactorily on Windows 95, 98, 2000 and ME operating systems.

It requires at least 1024 x 768 pixels of screen resolution.

The simulator can be downloaded from www.ruf.dk/rufsim.exe

3.1.4 Fleet management for Lausanne (SSA)

Develop the fleet management of the Lausanne experiment

3.1.4.1 Objective

- To test and evaluate the Traffic Manager HB® on the Pilote of Ouchy

3.1.4.2 Operational goals

- Test the developed Algorythm
- Optimise the delay time between demand and real transportation
- Test on 3 capsules in the 1st step
- Test on 10 capsules

3.1.4.3 Baseline reference

- The Traffic Manager HB® is an application of the system Manager Hyperbird®

3.1.4.4 Deliverables

- Description of the results obtained on the Pilote

3.1.4.5 Description

3.1.4.5.1 Management of a line or of a grid

The electrification of road allows to follow capsules from a dispatching centre at any point in traffic and to check on the computers of command of the system that administers the organization of the traffic according to the demand. The system can be run in a fully protected lane or in a partially protected site.

In the second case capsules move, for instance, on both sides of the road without a need to reinforce the road. They are separated from road traffic and protected by a low wall or a natural barrier. The speed is quite high (18 km/h).

At crossroads, capsules cross with the "pedestrian phase" at reduced speed. The speed is also reduced when the route runs in a pedestrian zone (7-10 km/h). In that case, no measure of physical separation of capsules is required.

Traffic can be managed according to several modes that are described below.

3.1.4.5.2 Straightforward Management

3.1.4.5.2.1 As a continuous train

On lines with high demand, capsules closely follow each other to form a chain. This chain of capsules stops for instance about 10 seconds every minute to allow for loading and unloading at any point of the grid, along a continuous platform. In that case, the hourly capacity of a line in protected lane can reach up to 15 000 travellers in each direction (one person per meter for a commercial speed of 15 km/h).

3.1.4.5.2.2 Circuit "in step"

In that case, bubbles are sent into the circuit which is a closed loop connecting all the stations, with a fixed distance between them. This distance depends upon the number of capsules foreseen in traffic.This represents a stable frequency of passage of capsules at the stops.

In the absence of any disturbance, stop duration at loading points is of about 10 seconds each. The system is paced in hourly slices according to the demand, but may be disturbed either by traffic lights, where capsules have no priority, or by unexpected obstacles or short breakdowns. The dispatching centre automatically gives the rhythm again to the capsules at the origin of the circuit, in a way comparable to that of cable cars where cabins line up in a waiting position at the starting point. The system works like a classical line of public transport, but in this case, without drivers.

3.1.4.5.3 Dynamic Management, Origin - Destination

The dynamic management of capsules proceeds somewhat like that of an elevator. The latter offers to its user the choice of a destination : the desired floor., On the way, it picks up persons waiting on intermediate floors and drops off those who wish it. If nobody calls for the empty elevator, it sits in a waiting position.

With a much better service, the Serpentine system can be administered in this spirit in an extremely flexible and efficient way, by adapting itself to strongly variable demands in time and space. During some period of time, passengers may be rare on a line, but suddenly become very numerous at one or several stops. In the second case, necessary capsules and those closest to the users are re-injected upon demand. Waiting times are reduced to a minimum. During quiet periods, capsules are stored at several points on the grid or on the line to avoid having them circulating empty.

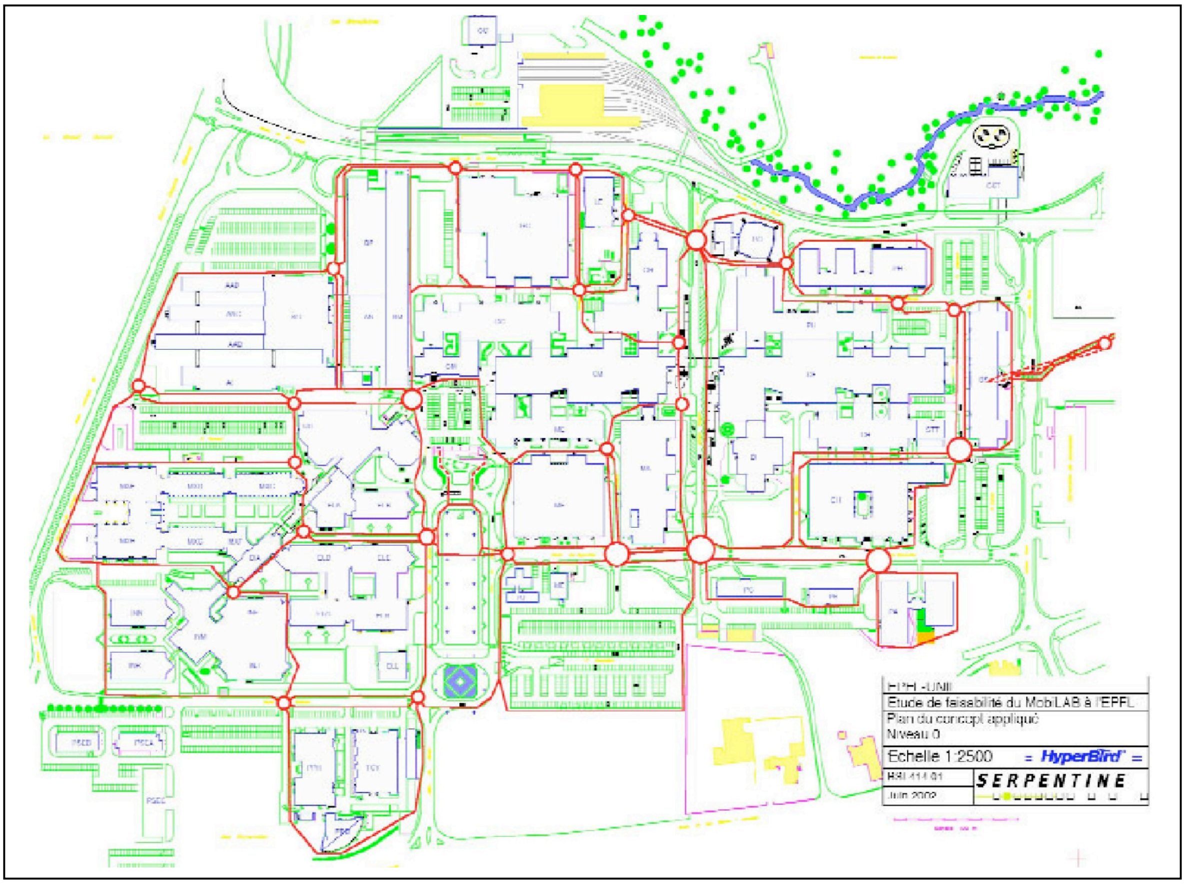
The traveller who boards a capsule gives his destination. If no modification of the order is given en route, the capsule moves on withou a stop, until it reaches its destination.

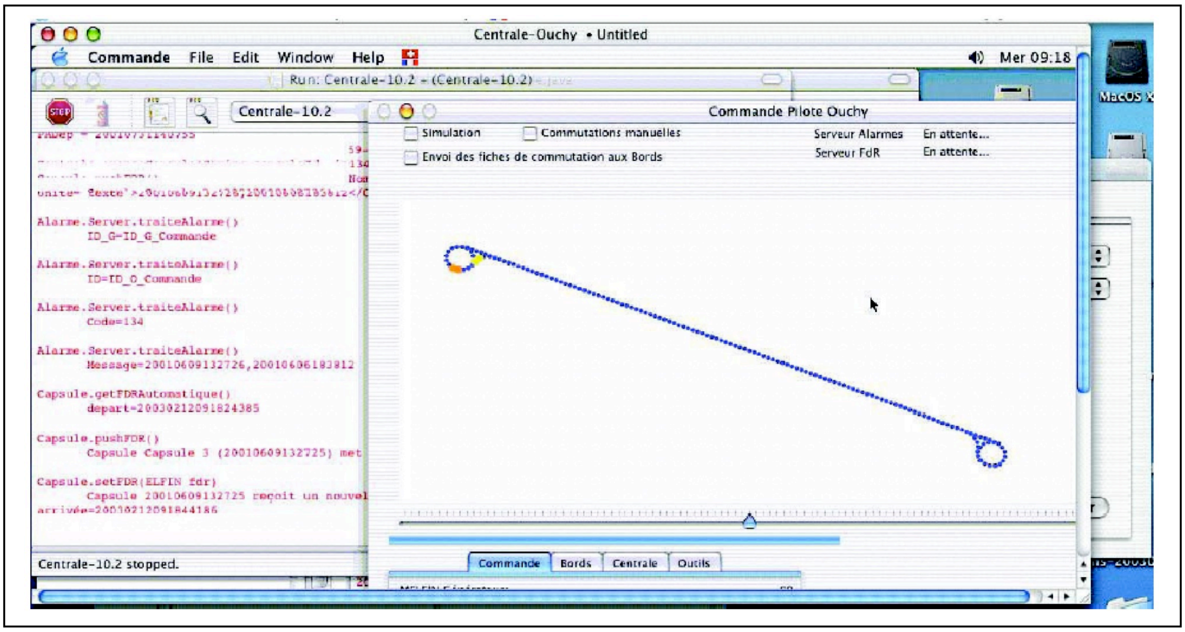
Ordering capsules at roadside stops can be done by means of a multimedia terminal or through a SMS message.

The user puts his finger on the touch-screen of the terminal and indicates the end point of his route. If he wishes, he can specify through which stations he wants to pass, in how much time (for bookings) and how many capsules are needed.

The terminal sends on orders to the dispatching centre that knows the availability of capsules and their location. It attributes one or more capsules for the required trip, according to the route and the schedule requested.

Capsules then leave their zones of storage and move automatically according to orders given to the terminal by the user.





The command module of the Magnétoglisseur® puts successively under tension the reels above which the capsule is. A device follows the passage of the capsule and informs the dispatching centre in case of delay or of an obstacle on the road. In this way, capsules can be fitted back in the circuit at switches, without difficulties. This device also ensures that distances are kept or that capsules remain synchronized in line if one of them does stop.

The realization of the demonstration site on Ouchy's quay has thus allowed to show that it is possible to introduce functions for the automatic management of the stocks, with anticipation of the demand.

3.1.4.5.4 Individual Traffic

Persons authorized to drive Serpentine capsules are allowed to leave the grid because capsules are equipped with batteries that supply current to the motors and with an onboard control system in a pocket computer.

Besides, the strips of road equipped with Magnétoglisseur that feed energy to the Serpentine capsules could also feed individual vehicles. In that case, the flexibility of use would be maximum.

3.1.5 Network model (UB)

See annex: **NETWORK MODELS FOR CYBERCAR TRANSPORT**

3.1.5.1 Description

For the present purposes it is necessary to develop a model which reflects demand over a complete city, rather than within a single corridor as analysed in the last section. Many cities demonstrate a trip demand density which increases towards the centre of the city. In the past smaller single centre cities had trip patterns which were dominated by the demand for trips to and from the centre. This is far less prominent today. Cities now are essentially mulit-centre, with a dispersed travel demand. Cox (2002) points out that the demand for travel to the centre rarely exceeds 10% of total trip demand in any city. Indeed, it is recognised that urban decay has led in some cases to "doughnut" cities in which the demand for trips concentrates on a ring some distance from the old city centre. Specific modelling of particular types of city may be undertaken as a second phase of the present work. However it is suggested that the assumption of a uniform demand over the complete city is an acceptable first approximation to many existing transport patterns. More importantly for the present purposes, it provides a simple starting point for analysis. It is believed that in practice details of demand patterns will only have second order effects on the results.

3.1.5.1.1 The Model City

European cities have a complex cellular structure, and transport results can be very specific to the particular city topology being considered. US cities are generally laid out on a grid pattern, at least in part. The grid pattern provides a helpful starting point for the present work since it simplifies the analysis usefully. It also provides a direct link to the linear model considered earlier.

The model transport system to be studied is for a city of prescribed size, in which all transport links lie on a square grid, running either N-S or E-W. This is shown in Figure 5. There is little additional loss of generality by considering a square city.

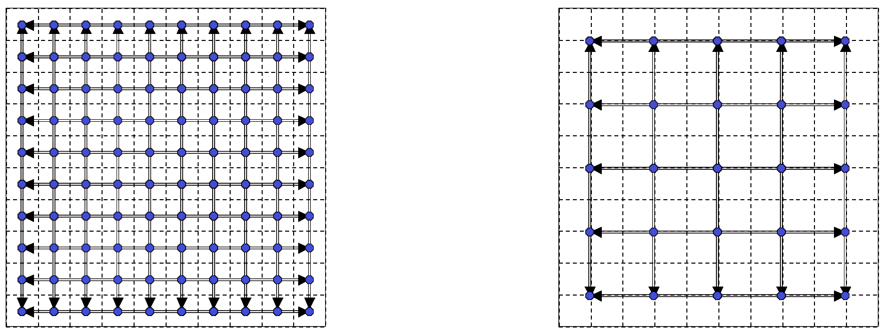
3.1.5.1.2 The Model Transport System

An idealised system has been specified to meet the demand. This follows ideas that have been put forward by several others, for example Cox (2002).

The system assumed consists of a series of vehicles which traverse the city bi-directionally, either North South or East West. Stops are located at each intersection at which transfers are permitted. Thus it is possible to get from any point in the city to any other with just one transfer. For the purposes of the present investigation, it is immaterial whether the routes are formed from bus, rail or indeed airborne links

In the example system shown in Figure 5a the square city is divided into 100 blocks 10x10 with a station at the centre of each block. This means that the length of each double track is nine blocks.

At each station, it is presumed to be possible to board a vehicle travelling N, S, E or W. It is also assumed that transfer is possible between NS and EW at each station. Stations at an edge have a restricted set of transfer possibilities.



a) 10x10 b) 5x5

Figure 5 Example Track Coverage

This appears to be a practicable system for many cities. It can be realised by a conventional bus or train, especially if the route network is segregated from other uses. However, a more effective realisation of the system could be fully automatic cybercars. This would permit the use of smaller vehicles since costs would not then be dominated by the cost of the driver.

There are a variety of issues in the design of such a system. Many of these are associated with detailed engineering, for example how to achieve effective transfer from line to line. However, for the present purposes such issues will be ignored. The principal concern of the present study is the determination of optimum scaling parameters. These include

1. Number of lines required to cover city. In figure 1a above a total of 20 tracks with 40 lines are shown. A larger mesh version of this is shown in Figure 1b. This shows a 5x5 matrix system with 20 lines. It is clear that the larger mesh system will involve longer walk times for the passengers, and large vehicles for their carriage. The optimisation of this is less clear.

2. Number of vehicles required on each line. For example in Fig 1a if it were desired to offer a transfer opportunity on arrival at every station then nine vehicles would be required on each line, each stopping at every station at the same time. Use of a smaller number of vehicles will result in less transfer opportunities. The issue is the trade off between lower cost and better passenger service.

3. There is also the question of the size of vehicle required to meet the demand under the various assumptions.

Answering the above questions will provide basic information of the relative benefits of basic scaling parameters on passenger service.

Algorithms and tools for fleet management and energy system (DITS)
The present section reports on the work conducted by DITS within the framework of the WP3 "New Technologies for Infrastructure", which addresses tasks 3.1 "Fleet management" and 3.4 "Energy systems". For further details on the work see Annex # to present deliverable.

DITS was intended to develop software tools for fleet management integrating the option of different energy systems in choosing localization of depots and recharging stations. In this way also Energy Systems task is addressed by means of models to simulate cybercars and allowing a-priori evaluation of their performances within a Cybernetic Transport System (CTS).

3.1.5.2 Objective

- To develop a software tool to design a CTS application by means of simulation of several scenarios, and to manage on-line CTS applications.

3.1.5.3 Operational goal

- Integrate the developed design tool to evaluate the operation of a particular system with the different available energy-systems.
- Integrate the developed management software for the optimisation of the operation

3.1.5.4 Baseline reference

- The tools produced in this task and in task 3.4

3.1.5.5 Deliverables

Planning and management tools.

3.1.5.6 Description

3.1.5.6.1 Problem definition

The problem is to design and manage a CTS (Cybernetic Transport System), an innovative transport system based on small automated vehicles, the CyberCars. Designing CTS means to determine, given the transport network and the demand, CTS technology to be used, features of fleet (number and type of vehicles), features of infrastructure (number and localisation of depots and recharging stations), features of service (tasks assignment, optimization of vehicles utilization, recharging strategies, maintenance, etc.).
Managing CTS means satisfying transport demand given in real time by means of dynamic assignment of tasks to cybercars (dial-a-ride system), monitoring status of vehicles and of network, including optimisation strategies for routes and for vehicles utilization.
DITS has implemented in one program two software tools to design and manage CTS applications. Developed program is named CTSDesign and it is described below. Considerations about energy systems and the Kernel module follow.

3.1.5.6.2 Description of CTSDesign

CTSDesing is an off-line tool for designing CTS applications given a transport problem. It receives in input transport network, demand, type of CTSapplication (vehicle technology, energy system, recharging technology) and variables having a range of possible values (number of vehicles, capacity of vehicles, number of depots, etc) and gives as output:

- Fleet dimension
- Capacity of vehicles
- Number and localization of depots, parking and recharging stations.

To do this the tool defines the exhaustive set of possible scenarios, being a scenario a combination of all variables defining the CTS application. By means of simulation courses and statistics it is possible to evaluate several scenarios in order to find the one who better satisfy customer requests.
CTSDesign has a modular architecture. Each module is a program and exchanges data with others. Modules and objects are described below having as reference the diagram depicted in Figure 1.

- **Static input**. Static input consist of demand and graph. The former is provided with O/D matrix prepared previously which relates to a certain time slot. It is possible to load several demand matrixes related to different time slots (e.g. morning, rush hours, etc.). Graph is built up by creating a network layer on a GIS map, defining nodes, links and related features.
- **Variables of scenario**. These are variables whose combination defines a scenario. They are: technology of cybercars to be used in CTS application (energy systems, guidance system, ect.), number and localization of depots and recharging station, admissible range of selection for number of vehicles and their capacity, financial data (installation costs, management costs, fares, ect.).
- **Operating modules**. These are dedicated programs or procedures to operate specific tasks during elaboration.
- **Requests Generator**. This program randomly generates lists of request on the basis of provided demand.
- **Scenarios definition**. This procedure loads variables of scenario and exhaustively combines them to generate all possible scenarios which are stored in databases together with vehicles information.
- **Simulation**. This procedure simulates system operations for each scenario, conduction several courses and storing results in databases. Such procedure invokes the Kernel, a particular external module which elaborates requests and assigns vehicles to tasks on the basis of ADARTW (advanced dial-a-ride with time windows) algorithm.
- **Scenarios evaluation**. This procedure evaluates all simulated scenarios using indicators and weights given in input by the user. It provides a ranking of scenarios. The first in rank satisfies most user requests.

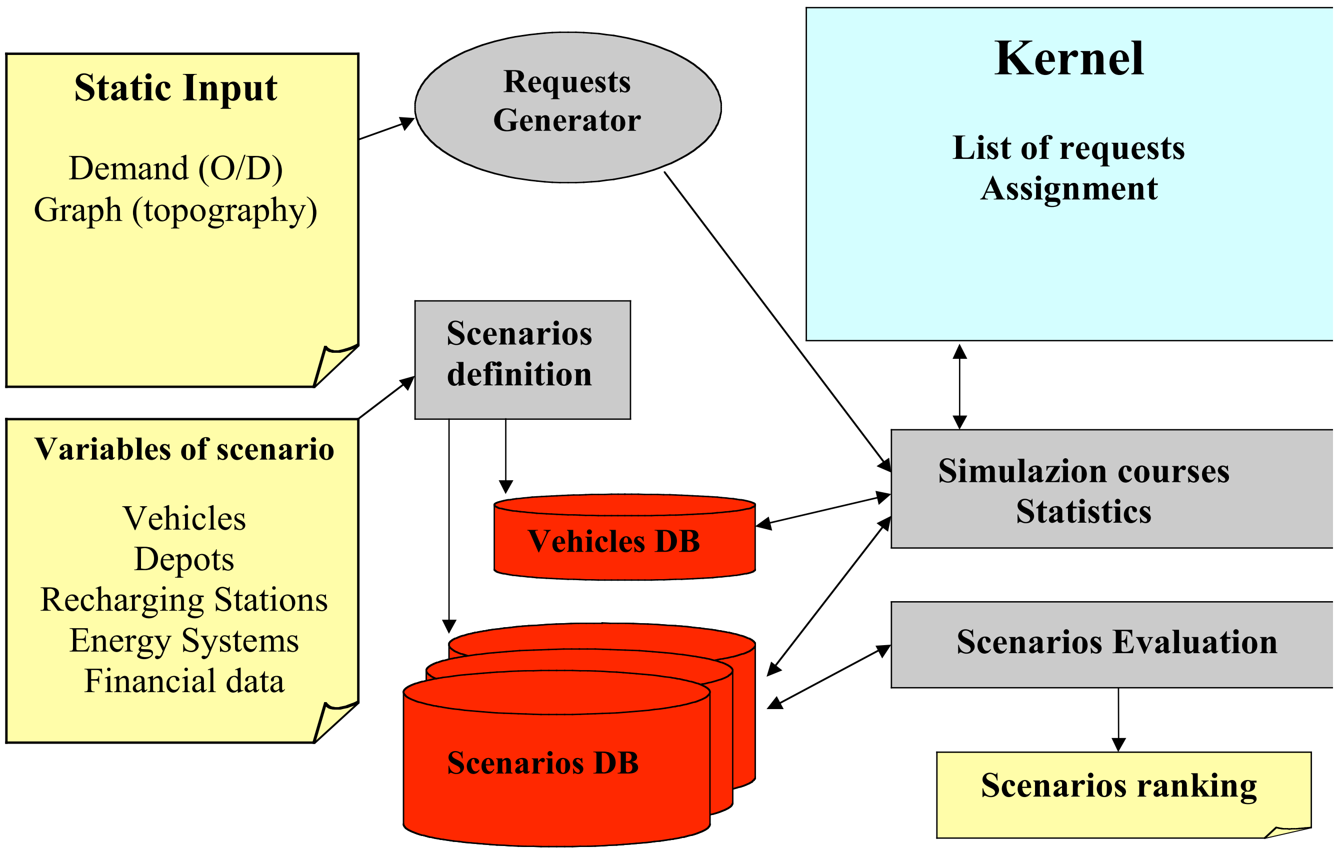


Figure 1 CTS Design modular architecture.

CTSDesign operates following three main phases:

1. Data input
2. Processing
3. Presentation of results

1. Data input

First phase is divided into three processes as depicted in Figure 2.

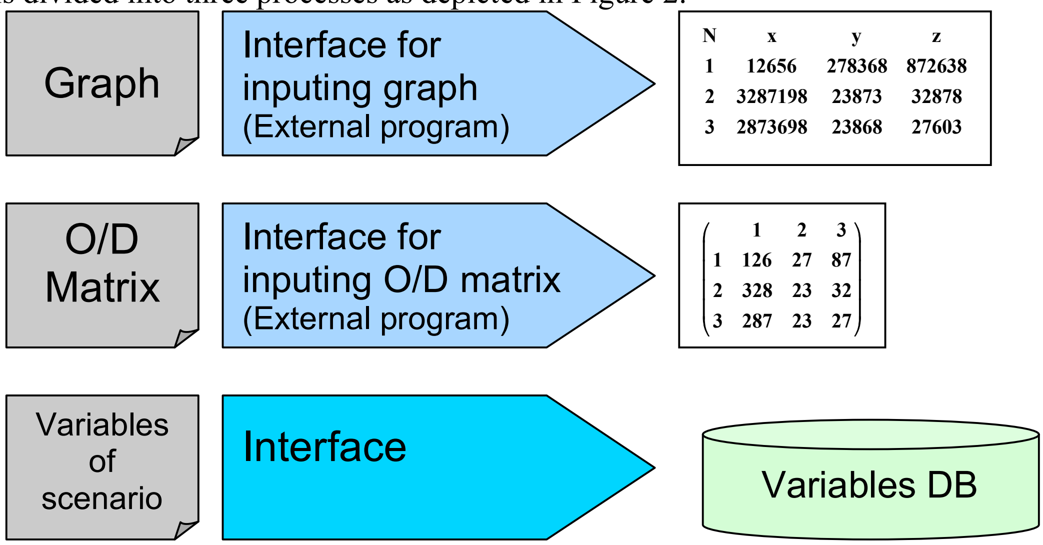


Figure 2 Data input process.

First process consists of input of the graph. Current release of the program needs to receive such graph in database format. In this way an external software is needed to create the graph from a GIS map and to generate a text file with coordinates of nodes and features of links.
Second process consists of input of the O/D matrix which collects the demand pertaining to a certain daily time slot. An external program has to be used in order to prepare the input file for CTSDesing.
Third process consists of input of variables of scenario (vehicles, depots, recharging stations, etc.) by means of CTSDesign interface (dialog box).
All data input can be categorized as reported in Table 1.

Table 1 Data input categories.

Category	Data	Notes
General data	Graph	(1)
	Kinematics of service (maximum speed and acceleration)	(2)
	Average time at stops for passengers boarding and alighting	(2)
Demand statistics	O/D matrix	(1)
	Time distribution of requests	(2)
	Number of lists of requests for simulation course	(2)
Lists and scenarios	Types of vehicles	(3)
	Lists of vehicles	(3)
	Lists of depots	(3)
	Lists of recharging stations	(3)
	Scenarios	(3)
Evaluation data	Operating period (years, days for year)	(2)
	Opportunity cost of assets	(2)
	Fares	(3)
	Non-financial indicators' weights	(3)

(1) Data loaded by means of text files; (2) data input by dialog box: (3) data sequentially requested by the program.

Data generated by the above mentioned processes are input data for next phase.

2. Processing

Second phase is divided into five processes as depicted in Figure 3.
First process consists of the exhaustive definition of scenarios. Scenarios are characterized by list of available vehicles, list of depots and list of recharging station. The first step to create a scenario is the definition of the type of vehicles. Each type is characterized by number of seats, technical data (mass, capacity of battery, recharging power, etc) and economic data (prize, cost by kilometre of guidance infrastructure, cost of maintenance, etc). Second step is the definition of possible lists of vehicle. Each list includes a number of vehicles of the same type. Third step is the definition of lists of depot and recharging station (capacity and location in the network). Once these lists are defined it is possible to create scenarios, automatically combining all lists (vehicles, depots and recharging stations) or manually.

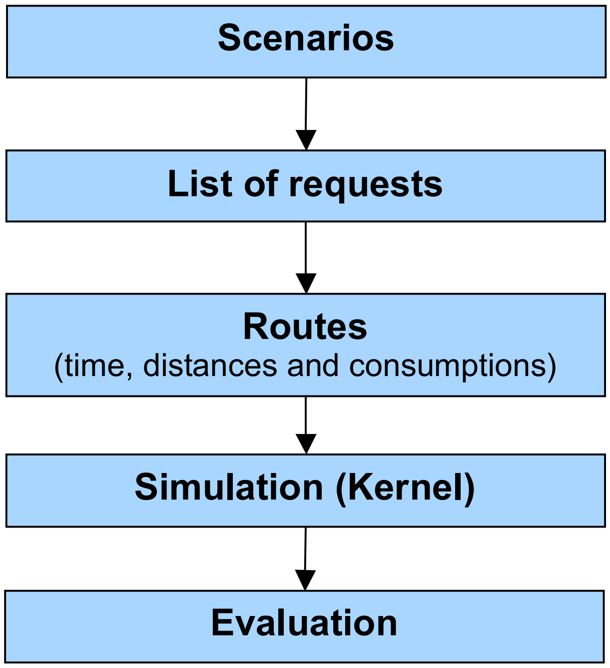


Figure 3 Processing phase flow diagram.

Second process consists of the generation of lists of request. Requests Generator is used to create ordered lists of request on the basis of O/D matrix and involving a model of requests distribution during the day. Random generation of list of requests can be made on the basis of different probabilities assigned to each type of request. Demand has to be represented by means of two three dimensional matrixes whose dimensions are respectively origin, destination and time slot of request. First step to generate a list of requests is the calculation of the number of requests to generate for each O/D pair. It is assumed that the number of daily requests is a random integer variable having a probability distribution similar to Gaussian distribution. Once the number of requests to generate is defined, generation of requests can start. Origin and destination nodes are randomly extracted (with the same probability) among those belonging to the same zone.

Third process is the creation of routes (best path choice). Routes are calculated for each possible O/D pair using the Ldequeue algorithm, which is based on the optimality principle by Bellman. The objective is to minimize the travel time. Travel time, total length and energy consumption are calculated for each obtained route and for each type of vehicles. Calculation results are stored in several matrixes which implement the database of routes used by the Kernel during simulations (following process).

Fourth process is simulation of scenarios. Simulations are conducted invoking the Kernel module based on DARP algorithm (see below). CTSDesign, once above mentioned input data are prepared, provide them to the Kernel. First of all, route matrixes (time, distances and energy consumptions) are exported and provided to the Kernel. Once a list of requests is transmitted simulation courses are conducted for each of determined scenarios. Results are stored in output files CTSDesign can load in order to evaluate scenarios.

Fifth process is the evaluation of scenarios. The implementation of a transport system involves an initial investment for vehicles and infrastructure, along with costs for management and maintenance, and incomes from fares, all these distributed during the operating years of the system. At the end of such operating period, a part of infrastructure or of vehicles could be eventually sold thus recovering residual value. Two kinds of evaluation are conducted: financial evaluation and socio-economic evaluation.

Financial evaluation is the calculation of the current total value of costs and incomes, given the number of annual working days and the life-cycle duration of the system. Average daily income is determined on the basis of results of a simulation course and of established fares. Annual income is derived by multiplying average daily income for the number of annual working days.

Costs can be divided into three main categories:
1. costs directly depending on the service provision (energy consumption, tyres, etc.);
2. periodic fixed costs (vehicle maintenance, insurance);
3. installation costs (vehicle and infrastructure).

Annual total cost is obtained adding annual costs depending on the service with fixed costs. Annual total cost is used to calculate the total current value in the number of operating years plus initial investment costs.
Total current values of costs and incomes are used then to calculate the following financial indexes:
- Current Net Value (CFV) = (Current Incomes Value – Current Costs Value). It is the profit (or loss if negative) deriving from the implementation of the project.
- Incomes/Costs Ratio (ICR) = (Current Incomes Value / Current Costs Value). It is the factor an investment is able to multiply invested capital.

Differing from financial evaluation, socio-economic evaluation considers not only incomes and costs, but also some non-financial issues, such as energy consumption, consequent environmental impact, travel and waiting time. Such issues are translated into financial terms on the basis of economic weights, in order to determine a Current Net Value.
Simulation results can provide additional information which are not directly related to the financial profitability or to the global attractiveness of a scenario, but which can provide directions to improve scenarios.

3. Presentation of results

Presentation of results is given on screen or optionally on text file. Results can be categorized in technical and economic results as follows.
Technical results:
- Percentage of served passengers in function of number and type of vehicles and recharging stations.
- Number of vehicles actually operated in each scenario.
- Average number of passengers on board of vehicles in different scenarios.
- Empty vehicles travelled distance in function of number and type of operated vehicles and its effect on total travelled distance of the system.
- Energy consumption (total, vehicles×km, passengers×km).

Economic results:
- Operating and maintenance costs [€/year]
- Acquiring and installation costs [€]
- Total costs (current value) [€]
- Total incomes (current value) [€]
- Benefits (current value) [€]

3.1.5.6.3 Energy Systems

Driving cycle

A vehicle running within traffic shows accelerations and decelerations, stops and starts. Its driving cycle is un predictable in detail. The simplest model is a trip with steady speed (as low as the traffic is intense) having low efficiency thus high energy consumption. For vehicles running in reserved lane, driving cycle

and energy consumptions can be predicted or planned with better approximation, by example, considering steady acceleration or limited jerk[1]. Between these two situations it is possible to individuate the case of a vehicle running on a non-reserved lane with poor traffic. With regard to the planned driving cycle such vehicle has stops and sudden slow down involving increments of travel time and energy consumption.
All these cases can occur for a CTS:
first case occurs when the service operates in a central zone with intense traffic. This is one of the situations best approached by a CTS system, which is devoted to decrease congestion by means of small vehicles (CyberCars) which can be shared by several passengers.
Second case occurs when reserved lanes are contemplated independently by the features of the area to be served.
Third case occurs in peripheral areas or areas with low density of population. In such situations a CTS can be useful (e.g. feeder service) in comparison with traditional systems in which acceptable waiting time is not consistent with economic utilization of vehicles.
Since it is only possible to implement CTS systems in reserved lanes (due to current legal framework), it is assumed in this work that driving cycle can be planned and then observed during the service. Driving on road network is modelled by a diagram of acceleration with steady steps (see Figure 4). Such condition, despite involves a perceptible jerk, is acceptable since standing in vehicles is not allowed.

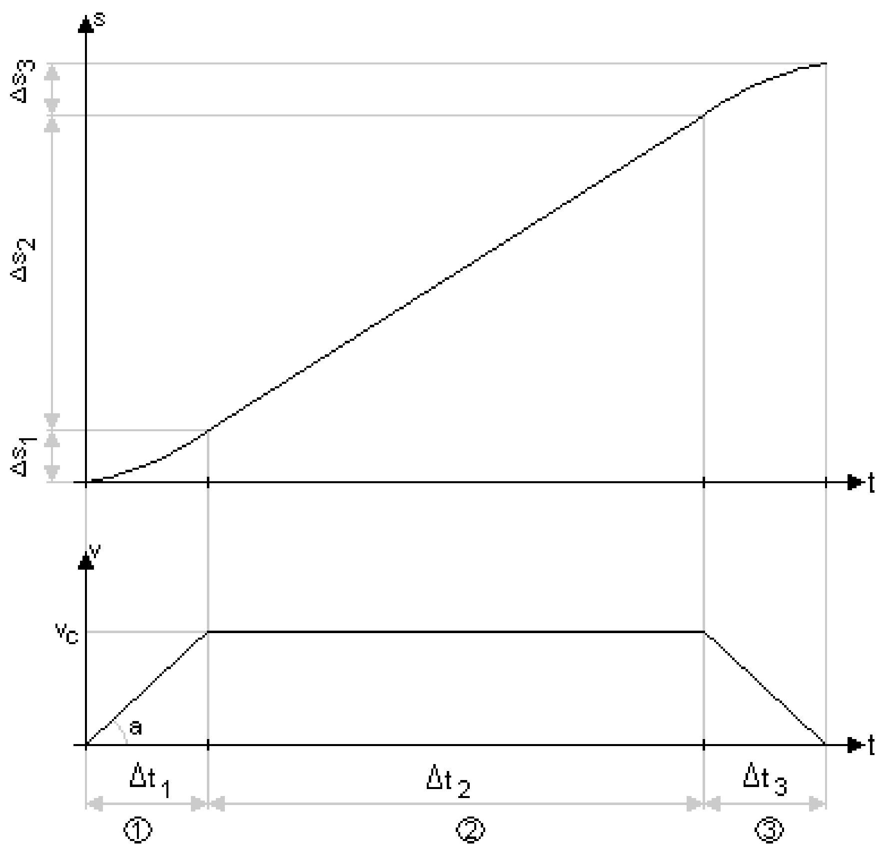


Figure 4 Driving cycle having acceleration with steady steps.

In such a diagram three phases can be distinguished:

1. Acceleration **a** from **0** to speed $\mathbf{v_c}$.
2. Optional steady speed ($\mathbf{v_c}$) segment.

[1] Limitation of jerk (derivative of acceleration) is important both for comfort and for safety of passengers.

3. Deceleration **a** from speed $\mathbf{v_c}$ to **0**.

Travel time and space in these three phases are:

$$\Delta t_1 = \Delta t_3 = \frac{v_c}{a}$$

$$\Delta s_1 = \Delta s_3 = \frac{v_c^2}{2a}$$

$$\Delta s_2 = \ell - \Delta s_1 - \Delta s_3 = \ell - \frac{v_c^2}{a}$$

$$\Delta t_2 = \frac{\Delta s_2}{v_c}$$

If $\ell = \frac{v_c^2}{a}$, Δs_2 is zero (also Δt_2 is zero) and the diagram becomes as in Figure 5, showing only acceleration and deceleration phases.

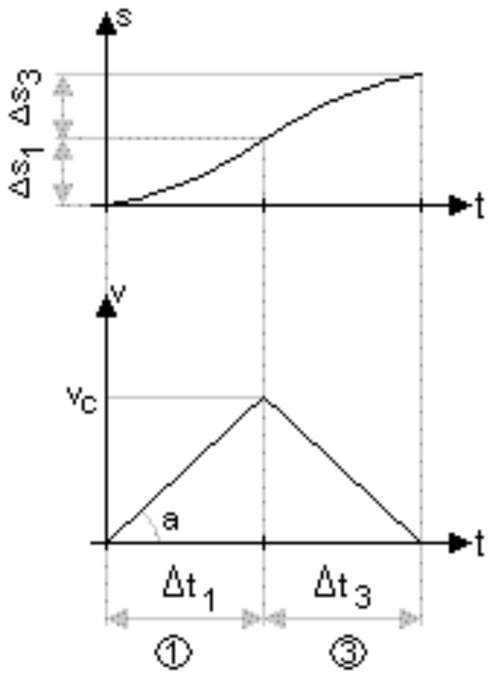


Figure 5 Particular case of driving cycle without steady speed segment.

If $\ell < \frac{v_c^2}{a}$ such diagram has still two phases but it is not possible for speed to reach value $\mathbf{v_c}$, therefore braking starts when speed is lower than $\mathbf{v_c}$. Travel time is $2\sqrt{\frac{\ell}{a}}$, and maximum speed is $v_{max} = \sqrt{\ell a}$. The related diagram is depicted in Figure 6.

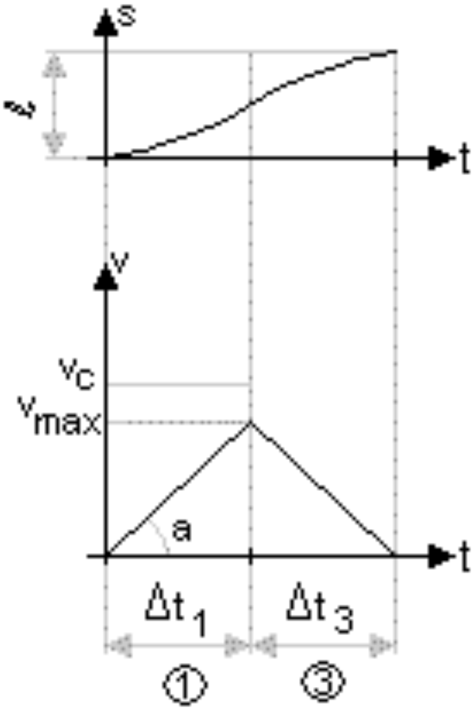


Figure 6 Particular case of driving cycle where speed $\mathbf{v_c}$ is not reached.

Since in general cybercars have slow speed in crossings, the driving cycle involving more than one links is approximated stating that in crossings vehicles slow down, stop and start again. A route on a graph is represented as shown in Figure 7. Time space P represents the eventual average waiting time at crossing due to a traffic light or to the traffic.

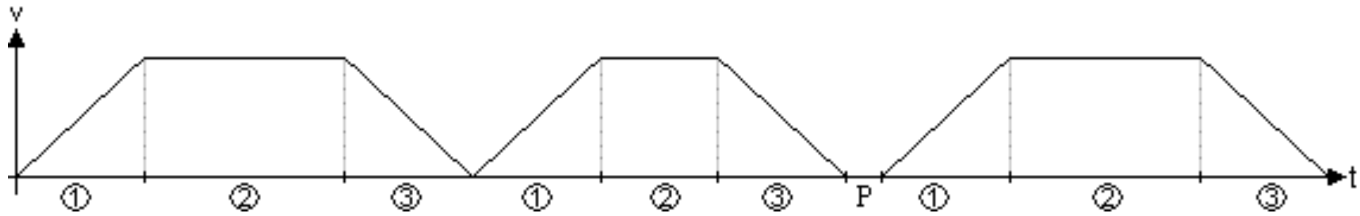


Figure 7 Driving cycle for a route with more than one links.

Energy consumption model

Analytical model is implemented to calculate approximately energy consumptions. Here a brief description is given, while a complete description is reported in Annex # of present deliverable.
First step towards calculation of energy consumption is the work of traction force. Energy consumed by a vehicle is derived from such work through the efficiency, which can be measured or provided by manufacturer. Second step is to consider all forces operating on the vehicle (resistance, inertia, gravity) and by means of second principle of dynamics to express traction force as the sum of such forces. Energy consumption is finally calculated as a sum of works due to forces operating on the vehicle.

Energy flow and efficiencies

Energy consumption model requires that the traction efficiency (ratio between traction work and energy derived from batteries) is known. In order to evaluate scenarios it is needed to know energy used by recharging system that is higher than the energy actually provided to batteries, because efficiency is lower than 1.

Simulation of the status of charge of batteries and of the energy consumed by the system is represented in Figure 8 by the diagram of energy flows.

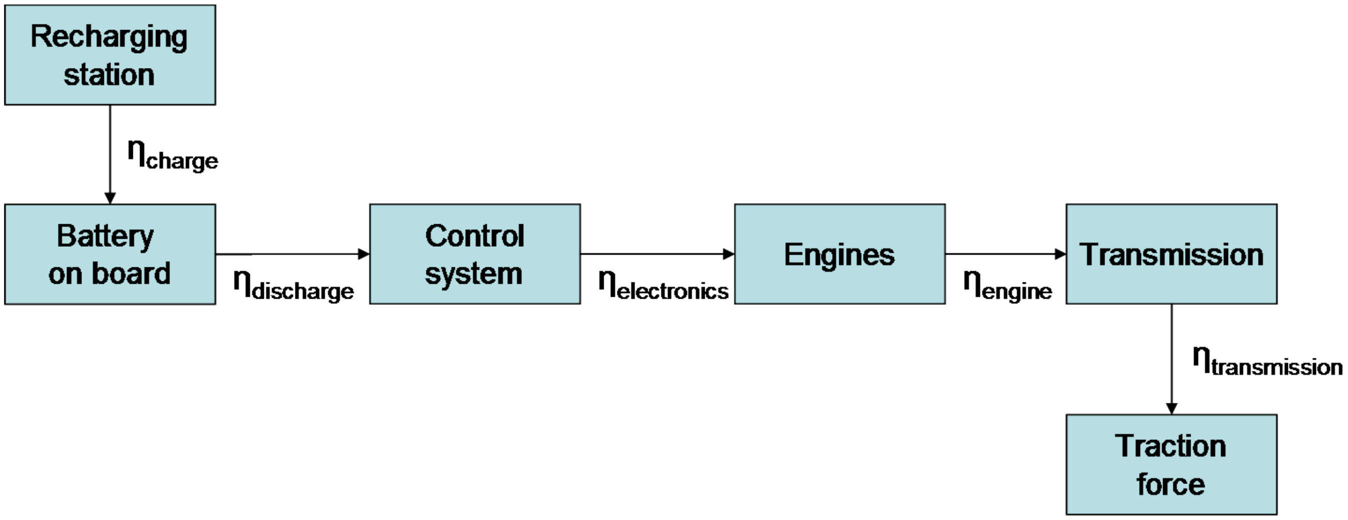


Figure 8 Diagram of the energy flow from recharging station to traction effort.

Traction efficiency of vehicle is the product of discharge efficiency, electronics of control system efficiency, engines efficiency and transmission efficiency. To calculate total energy consumption it is needed to consider also charge efficiency.

3.1.5.6.4 The Kernel module

As depicted in Figure 1, design software has a modular structure and operates all processes except simulations, which are processed by the Kernel module. This module provides assignment of vehicle to satisfy requests and simulates the entire transport service on the basis of the ADARTW (Advance-request Dial A Ride, with Time Windows) algorithm. Innovations were made to introduce the possibility of real-time management (On-line) of requests (*immediate-request* mode), and the energy consumption constraint to simulate electric vehicles operations, such as for CyberCars.

The Kernel module of CTSDesign software implements the algorithm developed to determine the best utilization of a fleet of vehicles in order to match transport requests. The problem is a generalization of the well known Dial-A-Ride-Problem (DARP), in which customers have to be picked in a specific point of the transport network and to be delivered to destination.
In particular it is proposed a heuristic algorithm to solve what it is known in literature as the *multi-vehicle*, *many-to-many*, *advance-request* (immediate-request) with *time windows* (ADARTW) version of DARP. *Many-to-many* means that each customer may have its own origin and destination, *advance-request* indicates that requests are received before preparing vehicles scheduling, while *immediate-request* indicates that requests are elaborated dynamically as they arrive (on-line management). *Time windows* introduce service quality constraints to guarantee that:
the passenger travel time does not exceed a pre-established maximum value;
the difference between the request and the actual pickup or delivery time is less than a pre-established value.

Each customer is allowed to request a pickup or delivery time. Requests have to be known before scheduling.
The problem is NP-complete and exact algorithms are not applicable to solve real cases (typically involving hundreds of customers to transport). The above mentioned algorithm uses parallel insertion to

assign customers to vehicles and provides good results to real cases in a few seconds with a common PC. A very flexible objective function allows to contain the cost of a service with pickup and delivery time very close to those requested.
The algorithm is derived mainly from the work of Wilson and Jaw. Vehicle routes are created by means of parallel insertion procedure of customers which uses a non-linear objective function. Main feature of dial-a-ride system is the possibility for customers to request a desired picked time (**DPT**) at origin or a desired delivery time (**DDT**) at destination. In this way customers are enabled to decide which time is better to constrain. It is expected a systematical trend in this choice. For instance in the morning most of customers probably request a desired delivery time at work, accepting departure time calculated by the system, while in the evening most of customers request a desired picked time at work. In this view a customer willing to be delivered in a certain point (e.g. station, hospital) at a certain time, is a DDT customer. Similarly for a DPT customer.
DPT represents also the time before of which customers cannot be picked. Similarly DDT represents the maximum time after which customers cannot be delivered. These hypothesis don't involve loss of generality and are convenient because for a DPT (DDT) customer the desired picked time (delivery) represents the beginning (end) of the useful time of pickup (delivery).
In such a dial-a-ride system the operator is supposed to pay particular attention to the quality of service. Consider, for example, a customer willing to be transported at 10 a.m. to a shopping centre reachable within 15 minutes by car. It is clearly not reasonable to deliver the customer at 8 a.m. as well as to make a 90 minutes trip. For these reasons the system operates complying with three service quality constraints:
No DPT (DDT) customer can be picked (delivered) before (after) its DPT (DDT).
Passenger travel time on board (ART) cannot be higher than a maximum value (MRT), where MRT can be expressed as function of direct travel time.
Difference between desired and actual picked/delivery time cannot be higher than a maximum value.
Maximum travel time on board and maximum deviation from desired time can be assigned arbitrarily by operator or can be negotiated each time with each customer. In this case the operator could inform his customer that travel time on board will absolutely be not higher than double the direct travel time, while pickup (delivery) will occur most 20 minutes in advance (late) than the desired pickup (delivery) time.

Energy problem

Insertion of new customers always occurs between two recharging stops (A and B). These stops coincide with departure depot and arrival depot, and related timetable refers to initial time and ending time of availability of such vehicle.
Each time a customer is inserted in a vehicle, the energy status is checked at recharging stations. If an energy consumption higher than a fixed level is revealed, for example, in B, a procedure is invoked in order to insert a new recharging stop between A and B. Such procedure operates as follows: the first attempt is to insert a new recharging stop just before the station in which the level is violated (B); if this is not possible, slack periods between A and B are checked from B to A. If a slack period has a duration allowing a detour to the closest recharging station plus the time needed for recharging, and if the insertion of such recharging is efficient (the energy status in B results lower than the threshold), then it is possible to insert the recharging, otherwise following slack period must be checked. If it is not possible to insert a new recharging station, then all subsequent insertions between A and B are not-admissible.

On-line mode

Present release of the algorithm elaborates requests dynamically one at a time on the basis of the time these arrive. The fundamental difference in comparison with the previous off-line release is the definition of the quantities each stop can be delayed or advanced by to allow the insertion of new customers. In particular, each time a request arrives (a customer is processed), such quantities are calculated again taking into account that no changing can be made in events occurred before actual time or which are going on.
For example, customer i pickup (+i) cannot occur within two stops +k and +m, not only if picked time of customer k is lower than actual time, but also if, being pickup of customer k not already done, vehicle

left at present the previous stop and is on the way for pickup of k. This is true for all events which can occur, and not only for insertions. For example it is possible to insert a recharging in a previous time, or to move back a schedule group if one of them is already done.

3.2 Human-machine interface (INRIA)

3.2.1 Improved hardware and software

New (or improved) hardware and software for man-machine interface for the users (both on-board and off-board)

3.2.1.1 Objective

To offer cybercar users a clear, intuitive way to call/reserve a trip

3.2.1.2 Operational goal

- Develop off-board HMIs by integrating wireless communications and portable devices like PDAs and smartphones
- Develop an ergonomical on-board HMI
- Test new interface technologies like touch-screens and speech recognition
- Integrate cybercar HMIs with other services (e.i. web services)
- Handle security functionalities like user authentication

3.2.1.3 Baseline reference

Praxitèle web user interfaces and on-board HMI in Frog APM

3.2.1.4 Deliverables

HMI software and concepts for CTS specificity, User tests, Wireless communications evaluation, Technology selection regarding on-board and off-board hardware and software

3.2.1.5 Description

The Human Machine Interface conceived for the CTS infrastructure should offer an easy, intuitive way for any user to call a trip.

As ways to reach information services are becoming more and more diverse, so the CTS service ought to be available from different types of devices: from fixed kiosks or desktop computers to portable mobile devices linked to the internet (or VPN) in a wireless mobile network.

3.2.1.5.1 User procedure

The user basically schedules a trip by tapping origin and destination on a graphical interface representing the cybercar circuit. Such interface does not show the position of the vehicles of the fleet.
Cybercar HMI actually interacts with the central fleet management station, which is the critical element in charge of managing at the same time user calls and the real-time vehicle routing.

3.2.1.5.2 Graphical User Interfaces

For on-board HMI, a program written in the Tcl/Tk language was used to handle a graphical interface to indicate trip destinations. This program runs in the in-vehicle computer which is also responsible for the cybercar automated guidance and obstacle detection functions.

Off-board devices consist in web interfaces. As central fleet management system goes to operation, the interface may replicate that of off-board use, using an in-vehicle router to the wireless network.

3.2.1.5.3 Telecommunications

Concerning off-board HMI, small portable devices (PDA) were at first tested in a Wi-Fi (IEEE 802.3b) wireless LAN.

Network equipment was not prepared for outdoor use and limitations on distance for signal availability and roaming were registered. Soon a new outdoor (specialized) Wi-Fi deployment will cover a part of the experimental cybercar circuit in Rocquencourt, for further developments in HMI aspects with a Mbps order bandwidth (3 to 10 Mbps).

Nowadays smartphones are being used for cybercar HMI purposes. They work with web forms downloaded from a public server, via a GPRS network. Even if throughput is of 9600 bps, results are excellent due the reliability and coverage of the cellular infrastructure operated by a telephone company. GPRS, which also handles connection points well, is also used in vehicle-server connection for cybercar fleet management.

Fig. Image of INRIA circuit on P800 phone

3.2.1.5.4 Prospective work

Future work will integrate new components, like speech interfaces and touch screens, which are currently under construction in INRIA research teams involved in ambient intelligence development.

Security functions by means of authentication management, but also trip secure validation and possibly fare management are going to be studied for further inclusion in cybercar HMI.

3.2.2 Shared vehicles in urban environments (CRF)

A study of an improved Human Machine Interface for the use of shared vehicles in urban environments has been carried out. Such activity allowed to develop a specific interface, which includes an output device and secondary controls (hardware and software) to allow the setting of parameters and the information exchange. Issues for the integration of the HMI solution in a Cyber car have been investigated by means of a dedicated mock-up, according to the user needs evaluation previously performed in Workpackage WP1. Ergonomic and human factor requirements have been assessed and used to define the functional design rules for both the control elements and the displays. Moreover a more specific analysis of characteristics of the Cybernetic Transport System has been carried out.

3.2.2.1 Objectives

The objectives of the activity, starting for the qualitative results emerged during the first phase of the project, are:

- To design, following the User-Centred method, an HMI prototype consisting of a physical mock-up of the Cyber car (dashboard, anterior seats, auxiliary controls) and an on-board information system;
- To define by an ergonomic study with users some characteristics of the CTS service, related to the user interaction with the system.

More specifically the operational goals of this activity are:

- defining the design and ergonomic specifications of the Cyber-Cars physical mock-up;
- realising a virtual dynamic system installed in the dashboard, which allows comfortable posture, intuitive interactions and a simulated control operation;
- defining the characteristics, the layout and the logics of the working HMI, in an ergonomic way to allow users to interact with the on-board cybercars functions.
  In general, according to automotive practice, the following requirements have been considered for the system:
  - it has to be easy to learn;
  - it has to induce a low number of errors;
  - it has to be subjectively satisfactory;
  - it has to be efficient to use.

  The method used, for these purposes, is the “Iterative Design”.
- gathering, by means of structured questionnaires, the users’ attitudes, considerations and opinions about the Cybernetic Transport System and Service, in comparison with other types of Public Transport Services available in an urban context.

3.2.2.2 Baseline reference

A baseline solution consists of simple interfaces available for existing services based on CyberCars.

3.2.2.3 Deliverables

The following deliverables have been prepared:

- A video showing the users’ interactions with the cybercar prototype.
- An internal report describing the phases and results of the User-Centred Design of the cybercar prototype.

3.2.2.4 Description

Physical mock-up design

It has been decided to design not only the cybercars on-board information HMI system, but also a simple vehicle interior mock-up (Fig. 3.2.1), composed of the following parts:

- the anterior seats;
- the dashboard, where some input auxiliary controls and a colour display are located;
- the armrest, where the output device of the Cybercars information system and other input auxiliary controls are located.

The basic assumptions regarding the physical mock-up have been as follows:

- The user is a transported passenger and not a driver: therefore, the vehicle does not have ordinary primary commands like the steering wheel, pedals and gear lever;
- Good accessibility must be provided for a city use and for short trips, with frequent ingresses/egresses;
- The main command chosen is a rotary knob, allowing to control the display functions. It must be designed to guarantee the maximum articulation comfort for the arm. Other commands, for secondary functions, are placed on the dashboard and can be reached with an arm extension or a light bending of the bust.
- The dashboard must allow a good visibility outside, according to the current constructive criteria.

In view of these considerations, it has been necessary to evaluate the passengers' posture in the vehicle, by considering: ingress/egress, sitting posture, control reachability and outside view.
The study has been conducted by simulation, using the tool Abita2000®, a dedicated proprietary software to evaluate the dimensions and geometry of the internal compartment of any vehicle.
Then the identified project solutions have been investigated experimentally, consulting a small group of users and experts in Physical and Cognitive Ergonomics, in order to arrive to the final solution for the lay-out.

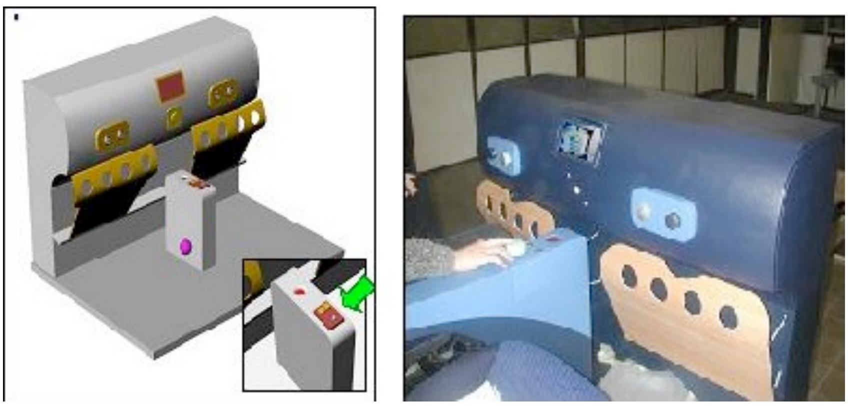


Fig. 3.2.1: Cybercar physical mock-up- virtual and final solutions

Short description of the final solution

The basic devices for the HMI are a rotary knob in the armrest and an LCD colour display in the central part of the dashboard. Additional switches or knobs are provided for the following functions: emergency call, operator call, volume control, temperature control. Loudspeakers and a microphone are included in the mock-up, to simulate communication with the operator (figure 3.2.2).

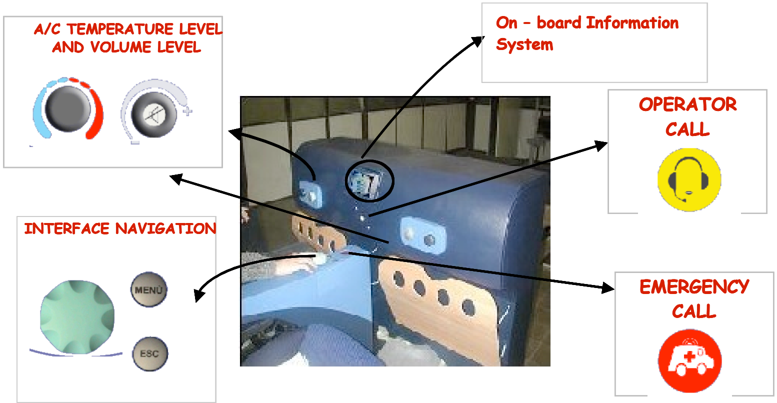
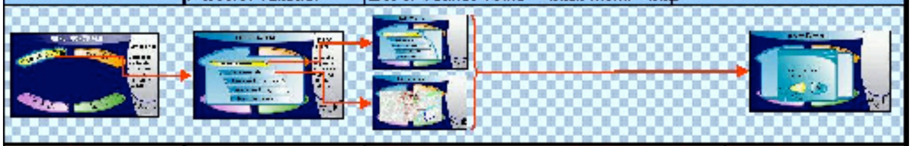


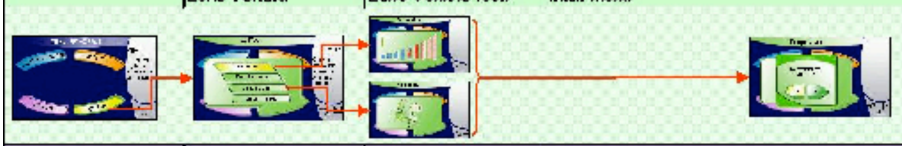
Figure 3.2.2: Devices for the developed HMI solution

Level 0	Level 1	Level 2	Level 3	Level 4
Destinazione	Scelta Fermate	*List of stops*	*Main Menu +Map*	
	Mappa Fermate	*Biggest Map*	Sub-Maps	*Main Menu +Map*
	Inserimento Manuale	*Keyboard*	*Main Menu +Map*	
	Scelta per Categorie	*List of categories: Shops, Museums, Stations etc.*	*List of adress for each category*	*Main Menu +Map*
	Percorsi Turistici	*List of Tourist Tours*	*Main Menu +Map*	



Level 0	Level 1	Level 2	Level 3	Level 4
Musica	Cerca Stazioni	Emittenti	*List of Broadcasting stations*	*Main Menu*
		Categorie Programmi	*List of Categories*	*Listi of actives broadcastin station for the specific category*
	Brani Mp3	Genere	*List of Kinds*	*List of pieces*
		Autore	*List of Authors*	*Main Menu*
		Titolo	*List of Tiles*	*Main Menu*
	Impostazioni	Automatico	*Main Menu*	
		Bassi	*Main Menu*	
		Alti	*Main Menu*	
		Zone Vettura	*Main Menu*	
	Volume	*Volume Icon*	*Main Menu*	

Level 0	Level 1	Level 2	Level 3	Level 4
Clima	Temperatura	*Temperature Icon*	*Main Menu*	
	Diffusione	*Air Diffusion Icon*	*Main Menu*	
	Ventilazione	*Ventilation Icon*	*Main Menu*	
	Zone Vettura	*Zone Vehicle Icon*	*Main Menu*	



Level 0	Level 1	Level 2	Level 3	Level 4
Servizi	Scelta Lingua	*Flags*	*Main Menu*	
	Credito Residuo	*Main Menu*		
	Check Vettura	*Main Menu*		

Figure 3.2.3: Structure of the interface

Regarding the architecture of the HMI system, a basic consideration has been that the Cyber cars could be used by people with different characteristics, like: elderly, young, with or without previous knowledge of telematics and electronics, inhabitants of the city or tourists that are there for the first time. Therefore emphasis has been given to a system design which can facilitate all the interactions. The organisation of the contents for the virtual interface are schematically shown in figure 3.2.3 (the labels reported are the Italian labels, used with the participants); the basic functions are: destination, audio, climate and transport services.

When the user gets into the cybercar for the first time, a short animation provides basic information on the interaction and shows what are the functions corresponding to each command on the dashboard and on the armrest. At the end of the animation the main menu is displayed. The users can chose between four options (Destination menu to insert a specific destination, Music menu to chose a radio station or a music, Climate menu to adjust the settings for air conditioning and Service menu to verify the use of the car, to change the language, to control the credit or the cost, or to check proper operation of the car). In each layer of the interface an Help menu is present which can give instructions about the options displayed (figure 3.2.4).

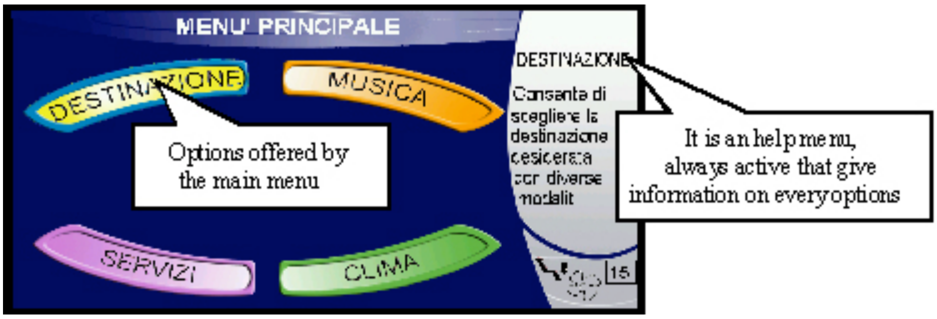


Figure 3.2.4: Options of the main menu and help function

In view of the specific application, particular attention has been posed to the strategies used by people to insert a destination. Taking into account the presence of users with different characteristics, in a number of cases the system offers more than one way to perform the same task.
Therefore the following aspects have been considered for the design of the Destination menu:
some people have a good representation of the geographic organisation of the city (so a modality with maps has been implemented);
other persons can remember the name of a street (so a keyboard has been implemented) a specific stop (so people can chose their destination from an exhaustive list of cybercars stops), or the name of a specific shop (so the people can chose their destination from an exhaustive list of shops, cinemas, banks, etc.), without knowing where they are located in the city;
other passengers can be tourists, with only a knowledge of some buildings or monuments, or simply they could desire to do a tour of the city;
Finally, a graphical organisation in the display has been designed coherently with the movements of the rotary knob, organising all the graphical objects on the interface in a circular pattern.

3.2.2.5 Evaluation of the HMI prototype of the on-board information system

Evaluation framework

The following aspects have been evaluated regarding the physical interface (1-3), the virtual interface (4-7), and the transport service (8):

1) mapping between the Input device and the graphical organisation
2) usability of the Input device (rotary knob)
3) usability and evaluation of the auxiliary controls and icons (self-explanation)
4) performance when interacting with the system at the different menu levels;
5) Learnability: the aim is to understand if people can significantly improve their performance within a short period of use;
6) Contents analysis, including logics and graphical features, adequacy of the services offered by the system, labels meaning and organisation of the labels;
7) readability of the information (i.e. adequacy of geometric and photometric parameters), pleasantness of the graphical design
8) Expectations regarding the innovative Transport Service offered by Cyber cars.

Fig. 3.2.5: Cybercar virtual interface

Participants

The evaluation has been performed by 24 persons, (20 males and 4 females), with an average age of 27.9 years (the youngest was 24 and the oldest was 35). The vehicle more frequently used by the participants is the bus (38.9%) followed by the car (30.6%).
Participants in general do consider a public transport system as a very necessary service in an urban context; present services are judged negatively, mainly because there are too many delays.

Experimental Design

In the evaluation, the following experimental variables have been considered:

A) Perceived Usability:

1) Users' attitudes and opinions about the physical mock up, virtual interface and transport service system: they were evaluated through a Semi-Structured Interview conducted during the test;

B) Measured Usability:

1) Deviation from Ideal Performance (efficiency): it was evaluated comparing subjects' performance times with a baseline time (repeated measures of experimenters' time performance);
2) Deviation from the first performance times and the other ones (learning): it was evaluated comparing the performance times registered when users have never tried the task before and after a quite long system exploration;
3) Number of navigation errors: it was evaluated using log files to record users' performances;
4) Users' satisfaction: It was evaluated administering two Post-Test Questionnaires.

The evaluation has been done using questionnaires (pre-test, post-test, final), a structured interview and recordings of the errors and performance times. A detailed description of the procedures is reported in the internal report.

3.2.2.6 Results

Adequacy of the physical interface

Considering the rotary input device and mapping with respect to the graphical information, in general people has considered the physical interface adequate with the scope of the Cyber Car HMI, except for the following considerations:

- the rotary knob is somehow slow, in a few cases (8 people);
- the rotary knob is a little coarse (3 people);

It was decided to quantify these considerations, with the post test questionnaire and results show that the rotary knob is considered by participants: Simple to use; Intuitive, also for elderly people; Useful; Somehow slow in some cases.

The results suggest that the rotary knob in general is adequate for this specific context, where driving is not foreseen. The situations in which the knob is considered slow are: the scrolling of very long list and the insertion of a word using the keyboard. The first problem has been solved eliminating the lists that are too long. The second problem has been solved using specific algorithms that increment the selection speed and also changing the torque feedback on the rotary knob.

Adequacy of the virtual interface

During the interaction with the system, the **efficiency** is defined as the deviation of the users' performance time from an ideal performance time. The ideal performance (baseline) has been measured by recording the time used by an expert during his interaction with the system (this is the best performance that is possible to perform).

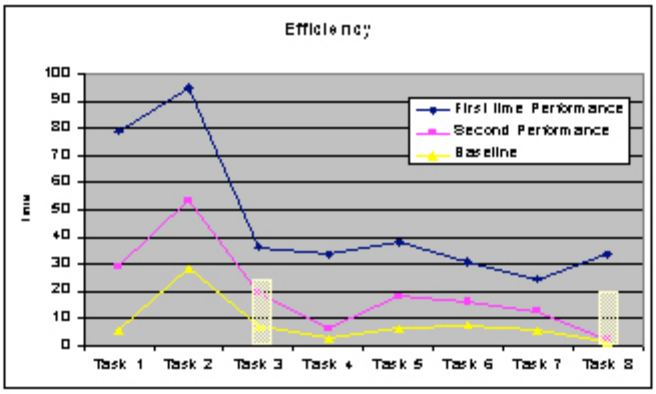


Fig. 3.2.6: Results of the tests: performance times for different tasks

As shown in the graph (Fig. 3.2.6) the performance time is significantly different from the baseline, except for the simpler tasks. The difference between these performances is due to the very deep knowledge that the expert had about the system. But in general we observe that after a period of use the performance approaches the baseline.

The error rate is not significant in the experiments, so it is possible to conclude that the interface is self-explanatory and does not need a specific training period. However, it can be observed that in the first time performance, users are interacting with a slower pace. But the first time performance is significantly different from the performance after the first interaction, except for the simpler tasks.
The conclusion is that the system is sufficiently simple, because the persons do not need a particular training to operate properly the HMI. In any case, with some practice, people reduced their interaction time, even if the first time performance is not so efficient as the baseline.

In general it is possible to say that the **contents organisation and the labels used** (chosen thanks to the evaluation of the low-fidelity prototype) are adequate, with the exception of a few cases regarding the wording in the 'music' menu, which have been judged inadequate and therefore changed.

From the evaluation, no negative aspects has emerged regarding legibility and readability of the information, thanks to a considerable attention given to these aspects during the whole design cycle.

Regarding the users' **satisfaction**, people has shown generally a positive attitude, considering the HMI: very innovative (56.3%) and consistent with their expectations (93.8%). Moreover, they have been satisfied after the use and they have considered the system easy to learn and simple to use.

The interviews and the post test questionnaires allow to highlight the characteristics that a **Cybernetic Transport Service** should have, according to people judgements.
According to people expectations about the Cyber cars service, it will be a little more expensive than other public transport services (particularly with respect to the bus, that it is the service more used by the specific sample of people). In contrast, people consider that the cybercars will follow more accurately the schedule, compared to existing Public transport.

A particularly positive image has been obtained, when considering the dimensions of safety, utility, relax and reliability.
The majority (43.8%) of people think that the Cyber cars should travel in special dedicated lanes, not open to other vehicles. Most of the participants (89.9%) think that this service should be active during both the day and the night. The majority (35.3%) thinks that the best way to reserve a cybercar would be by a mobile phone. Another way is to book it by Internet (32.4%).
The majority of people (42.9%) thinks that the best way to pay the service is by means of a credit card. As a second option (25.7%) people suggest the use of a specific rechargeable card.

People think that some specific services would be useful if installed on the cybercars: a tourist guide (29.4%), an information service (e.g. providing opening and closing hours of the public offices, shops etc.; 20,6%) and also a public telephone, even if they normally own a personal mobile phone (17.6%).
People think that the most important characteristics to be provided by the public transport service are: competitive costs (18,9%), comfort during the travel (15.6%), the availability of vehicles when needed (13.3%), low waiting time (12.2%) and a final indication of the amount of time to reach the destination (11.1%).

Finally, it is possible to say that the people have good expectations about the transport services based on cybercars, and they are not frightened about the possibility to travel in a car without a driver.

3.2.2.7 Conclusions

The major task within this part of the CyberCars project was to evaluate an HMI prototype for shared automated vehicles operating in an urban environment, using a specific mock-up and a user centred approach.
This objective has been achieved in the frame of Workpackage WP3 on technologies for the infrastructure, in particular considering the following aspects:

- The main functions which should be implemented in the vehicle are: to insert a destination, to control some entertainment features (audio and music), to control the climate in the compartment, to receive information on the service, particularly the good operation of the vehicle and data on the payments and the credit.
- Additional important features are a communication with the control centre and an emergency signal.

- An input device based on a rotary knob has been favourably judged, considering that no driving task is given to the user.
- An information system in the central part of the dashboard can provide an easy-to-use and effective interaction.

The choice to involve users' samples from the initial definition of the HMI up to the final prototype, passing through the iterative design, allowed to arrive in short time to the construction of the operating prototype, with a high usability and coherent with the users' expectations.

Going in more details on some design issues, the performed evaluation with subjects has indicated the following important design guidelines, which are especially referred to the specific application of Cyber cars:

- It is important to know the users' characteristic and general capabilities (e.g.: elderly people, young people, technology experts, tourists) in order to cope with them;
- The interface should use a simple and comprehensible language and an intuitive organisation, allowing to conclude any task in a few steps: the needs of people not leaving in the city (and perhaps of foreign people) should be considered, and an effective help menu preferably provided;
- Standard practices from the automotive field can be used for the following aspects: legibility of the text (but especially considering elderly people), feedback modalities, input devices. The same consideration applies for the accessibility and the ability to reach the controls. The absence of primary driving commands gives extra freedom to the designer.
- Multiple procedures for specific and rather complex tasks, such as the input of the destination, are a powerful approach to deal with different mental models of the users;
- A coherent mapping between the input devices and the interface graphics and structure is essential;
- The service based on cyber cars is appreciated and useful suggestions have been collected to better define its characteristics.

3.2.3 On-board interfaces (FROG)

Development and integration of on-board interfaces

3.2.3.1 Objective

Design and implement a Passengers Interface.

3.2.3.2 Operational goal

New (improved) hardware and software for HMI for the users

3.2.3.3 Baseline reference

Development touch screen based interface to:

- order a car
- choose a destination
- provide transport information
- provide in vehicle entertainment and area information:
- menu based
- self explanatory
- suited for different languages

3.2.3.4 Deliverables

System for the Rivium2 site.

3.2.3.5 Description

3.2.3.5.1 Station

Station is the place where passengers can ask for a car, etc, etc
On a station a CTS can be asked for via a control panel:

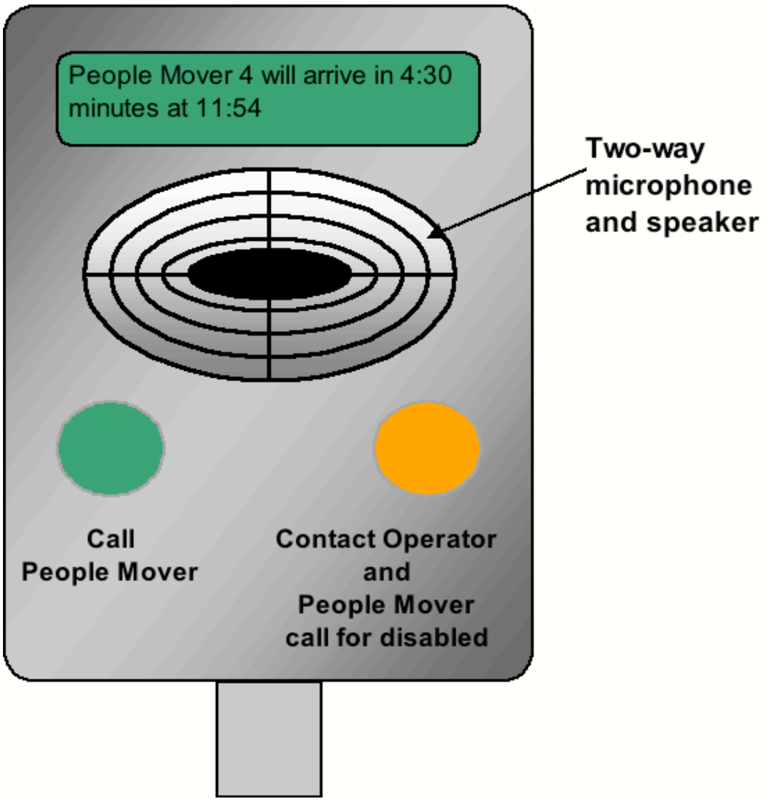


Figure 1: Call button console

The PM-call-button is mounted on a pillar. An additional information display returns the confirmation and other information lines. The display is a 2 x 40 character LCD-display. Apart from the messages on the dep./arr. display, this display shows messages concerning the People Mover call functions.

First line

"System in operation".
"System not in operation".
"System will stop in nn minutes".
Manual text from operator.

Waiting room

"Push button to call People Mover".

"Request in progress".
"Request acknowledged".
"People Mover will arrive in nn min.".
Manual text from operator.

Wheel chair
Passengers in a wheel chair require extra space in the People Mover. These passengers can call the operator with an extra call button. The operator can send an empty PM to this station. The Arrival/Departure display shows the remark "priority to disabled".
Arrival / Departure display
The Arrival / Departure display shows the message for the passengers at a specific station.

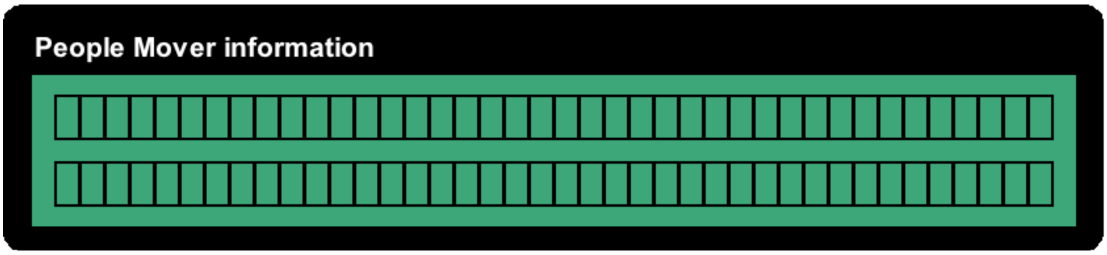


Figure 2: Arrival-Departure display

The display must be readable from a distance of 10 m and should have min. 2 rows of 40 characters and will show the following remarks :

First line

"Operation according to timetable".
"Operation according to request".
"People Mover not in operation".
"People Movers will stop in nn minutes".
Manual text from operator.

Second line

"People Mover will arrive in nn min."
Manual text from operator.

Security
Security's camera monitors the station for social security. More specifications are detailed according to the Communication infrastructure document.

Emergency precautions

Fire alarms
Each door on the platform has a fire-alarm button this button warns the operator and opens all doors at the platform. The tourniquet is always open to leave the platform.

Waiting room
The following ways can be used in emergencies :
wheelchair door[2],
boarding doors to People Mover (when PM has left the station),[2]
entrance tourniquet in opposite direction,

[2] Only when fire alarm button has been activated

exit tourniquet in exit direction.

3.2.3.5.2 Vehicle

3.2.3.5.2.1 Select vehicle destination

The passenger looks up the destination he wants to go to on the destination selection panel (user console) in the CTS. A push button is present for selecting this destination.

If the light associated with the push button is off, the passenger can use the push button to request a transport to this destination. When done, the light will start blinking green.
The VCS contacts SuperFROG (the supervisory system) to inform SuperFROG about the requested destination.
After some time, SuperFROG responds normally with a confirmation of the request. In that case, the light will remain steady on green and the CTS will at some later time be directed to the corresponding destination.
If the CTS has no alarm condition or pause status condition and SuperFROG does not respond within 30 seconds, the destination request is removed and the light returns to off. This situation normally indicates that communication with SuperFROG is failing or that SuperFROG is down.
If a station is not reachable, SuperFROG broadcasts this event to all CTSs, which activate a red light associated with that destination. Also at the user console display a message is shown.

Every time a destination button is pushed the buzzer gives a short beep (0.25sec). If the destination is accepted the buzzer gives a short beep (0.25 sec). If SuperFROG refuses the destination the buzzer gives a longer beep (2 sec).
Pushing a destination button which already illuminates red gives also a longer beep (2 sec)

Selection can be made at any time, during a stop at a station and during driving. After every selection FROG will contact SuperFROG. SuperFROG schedules a stop at the desired station.
If the vehicle is approaching a DECISION POINT, SuperFROG decides what the CTS should do, for example: continue to follow the main path or take a side path and stop at the station.
If a destination is selected while the CTS is inbetween the DECISION POINT for that destination's station and the projection of the station stop point on the main path, the CTS shall not stop at that station. The request will be rejected.
Destinations selected while the CTS has passed the station in the current route will be planned in the new route at the end of the current route.

3.2.3.5.2.2 Use intercom

The passenger shortly depresses the push button of the intercom in the CTS. As a result of this the remote operator gets a conversation request signal from his intercom. The remote operator acknowledges the request by operating his intercom, after which the bi-directional communication between the passenger and the remote operator is possible. Communication stops when the remote operator closes the connection.

The intercom recognises a scream and activates it self and gives a signal to the VCS. The VCS gives an alarm to SuperFROG.
SuperFROG arranges that:

- the camera view of the door region is automatically put in the foreground for the supervisor
- camera shots of the door region are automatically stored
- the intercom is automatically switched on

- the sound signal of the CTS's intercom is automatically recorded

3.2.3.5.3 CTS door functions

3.2.3.5.3.1 Open the CTS door

The passenger can request to open the automatic door by depressing the 'door open' push button inside or outside the CTS. The VCS will open the door only if the CTS is standing still and has no intention to start driving.
The doors open automatically after arriving at a station and stopped completely. The VCS will notify the passengers that the door is about to open between 2 and 3 seconds before the door starts opening automatically by giving an audible warning signal inside the CTS.
If the door is blocked during closing, the door opens automatically.

3.2.3.5.3.2 Closing the CTS door

The door closes automatically 6 seconds after they were fully opened. . An exception is made when the CTS is waiting at a station, the inside temperature is over 25 °C and the weather report does not indicate that it is raining. In that case, the doors remain opened, until a new mission is received.

If the door opening is blocked, the doors remain opened and do not close within 3 seconds after the last time the doors or the door opening was blocked.

The VCS will notify the passengers that the door is about to close between 1 and 2 seconds before the door starts closing automatically by giving an audible warning message inside the CTS. This signal is not repeated while the door is blocked, but will be repeated if the doors are going to be closed again after the door has reopened due to door blockage;

3.2.3.5.3.3 Safety at CTS door

For safety reasons the door is equipped with a 'door opening free' sensor and pressure sensitive strips on the edges of the doors. If these sensors detect something during closing, the door controller will open the door.

3.2.3.5.3.4 Misuse doors

If the doors have been blocked continuously for more than 15 seconds or if door closing has been interrupted for more than 4 times, the VCS raises a phase 2 alarm to warn the remote operator that something is wrong.

In that case:
- a warning signal sounds inside the CTS (user console beeper)
- a warning signal sound outside the CTS (beeper)
- pre-recorded audible message insite CTS: " attentie de deur kan niet sluiten, de deur is geblokkeerd"
- message at interior display: "DEUROPENING GEBLOKKEERD"

The messages and the warning signals remain active until the door closes

SuperFROG arranges that:

- the camera view of the door region is automatically put in the foreground for the supervisor
- camera shots of the door region are automatically stored
- the intercom is automatically switched on
- the sound signal of the CTS's intercom is automatically recorded

3.2.3.5.4 Push fast stop button

The passenger can push on a fast stop button inside or outside the CTS to make an immediate fast stop. There are two fast stop buttons in the vehicle interior, one on the user console and one near the wheelchair position. After pushing one of the internal fast stop buttons, the CTS command a pre-recorded audible message inside the CTS: "attentie noodstopknop ingedrukt"

There are four fast stop buttons mounted on each corner of the vehicle exterior.
Pushing results in a fast stop. After pushing one of the external fast stop buttons, the CTS command a pre-recorded audible message inside the CTS: "attentie noodstopknop ingedrukt"

The faststop buttons do not lock after pushing, but the status of the CTS remains "fast-stop active". The passengers can not reset the "fast-stop active" status, only authorised personnel can.

The user console exists of:

- information display
- destination buttons
- interior intercom
- fast-stop button

3.2.4 Interface for access to a system (Ruf)

RUF has been working on development of the necessary interface for access to the system. Access is interpreted as both the electronic interface and the physical interface (doors).

3.2.4.1 Objective

The objective or the work is to show possible solutions to the system access problem

3.2.4.2 Operational goal

Several suggestions for electronic interface for access will be described.
A solution to the physical access will be shown.

3.2.4.3 Baseline reference

Simple smart card electronic interface
Simple door systems in busses

3.2.4.4 Deliverables

Visualisations of electronic interfaces

3.2.5 Description of special door solution for maxi-ruf

3.2.5.1 Description

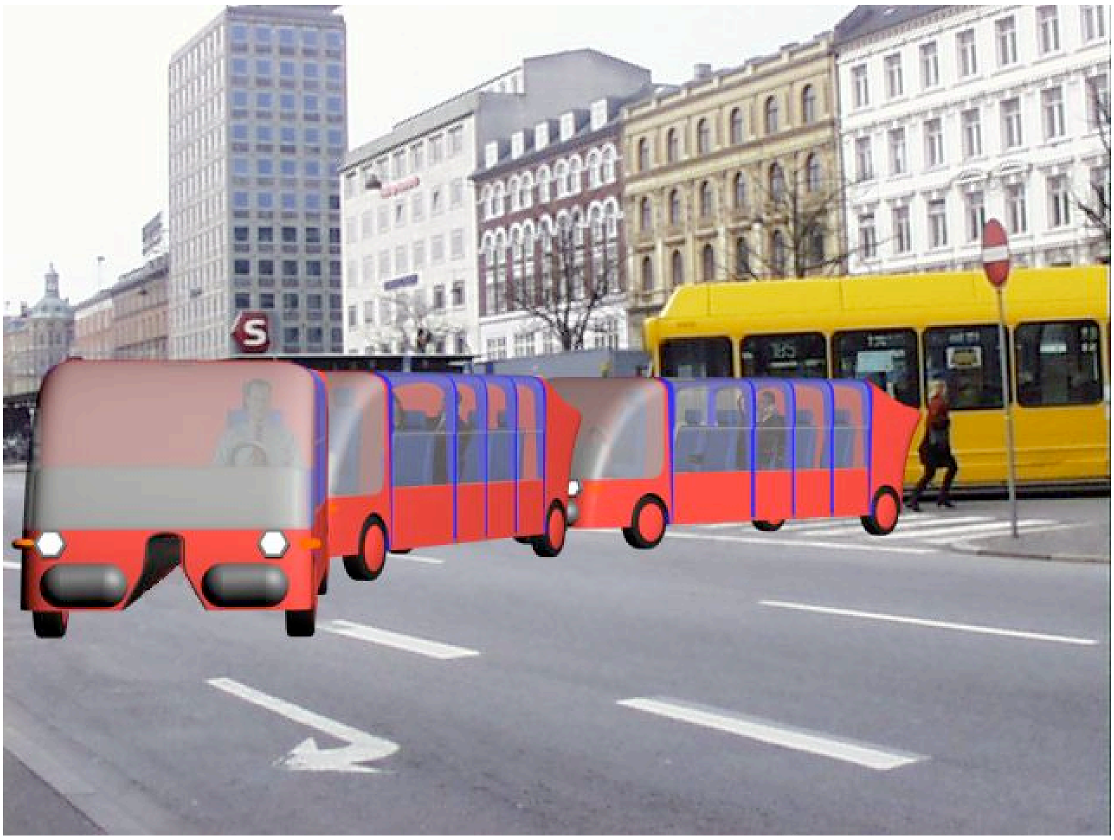
Electronic interface

It is known from traditional public transport to use smart cards in stead of tickets in a normal bus system. This is an improvement compared to normal tickets since the same card can be used again and again.

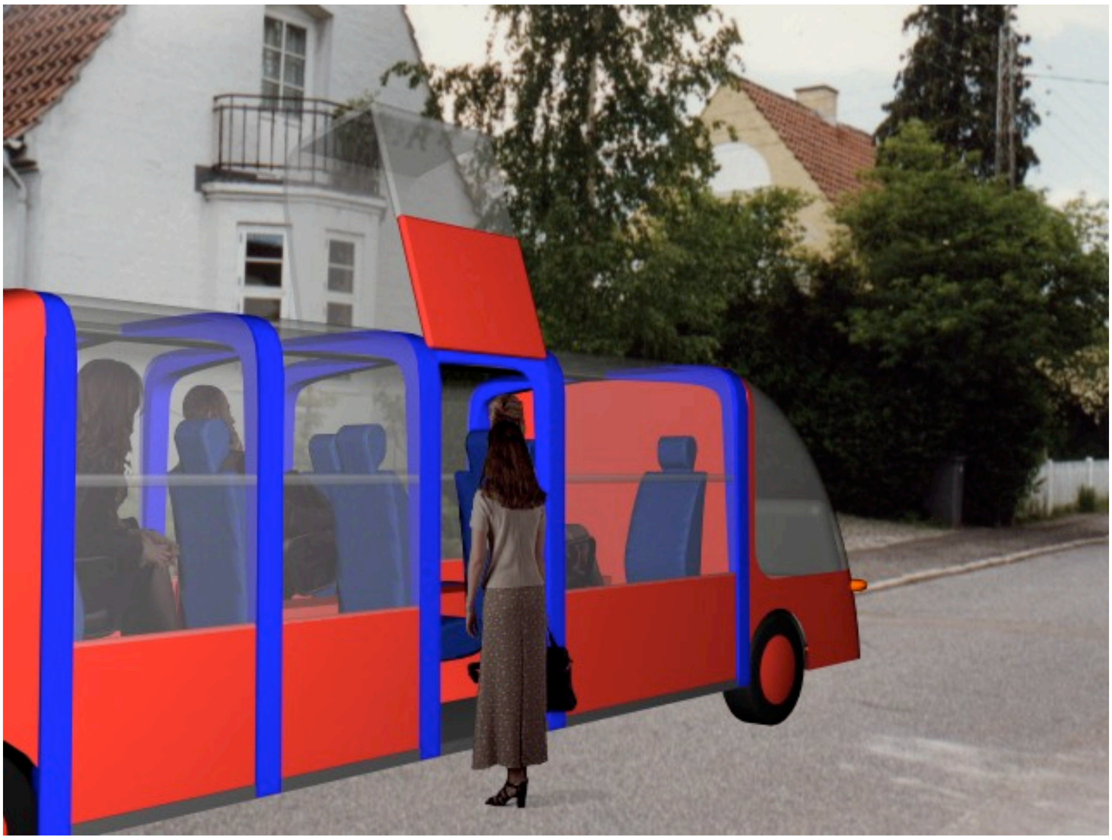
It is not relevant to use electronic devices for other facilities in a normal bus system, since the bus cannot respond to individual demands.

In a demand responsive system as the RUF public transport system, the system operator can fully use the internet and other electronic services available. There are several reasons why this is possible in a RUF system:

1) The maxi-ruf is a small bus (10 passengers). This means that it is possible to make a dial-a-bus solution where passengers can be collected at or close to their destination. If needed, the maxi can be coupled together with others to form an articulated bus with up to 3 maxi-rufs driven by one driver.

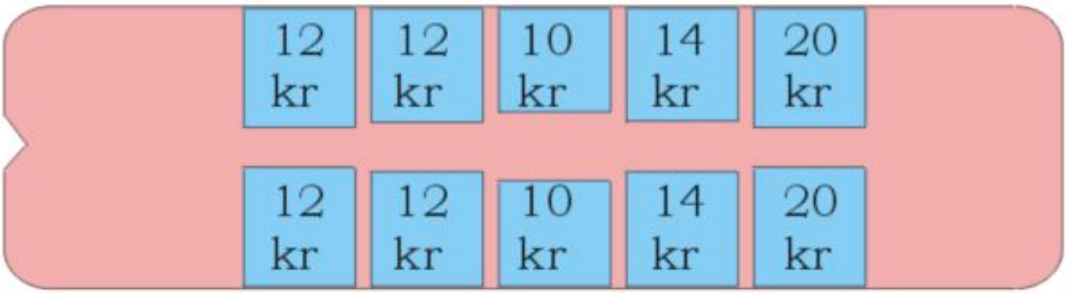


2) The main part of the RUF system is automated, so the chauffeur salary can be avoided for most of the trip length.

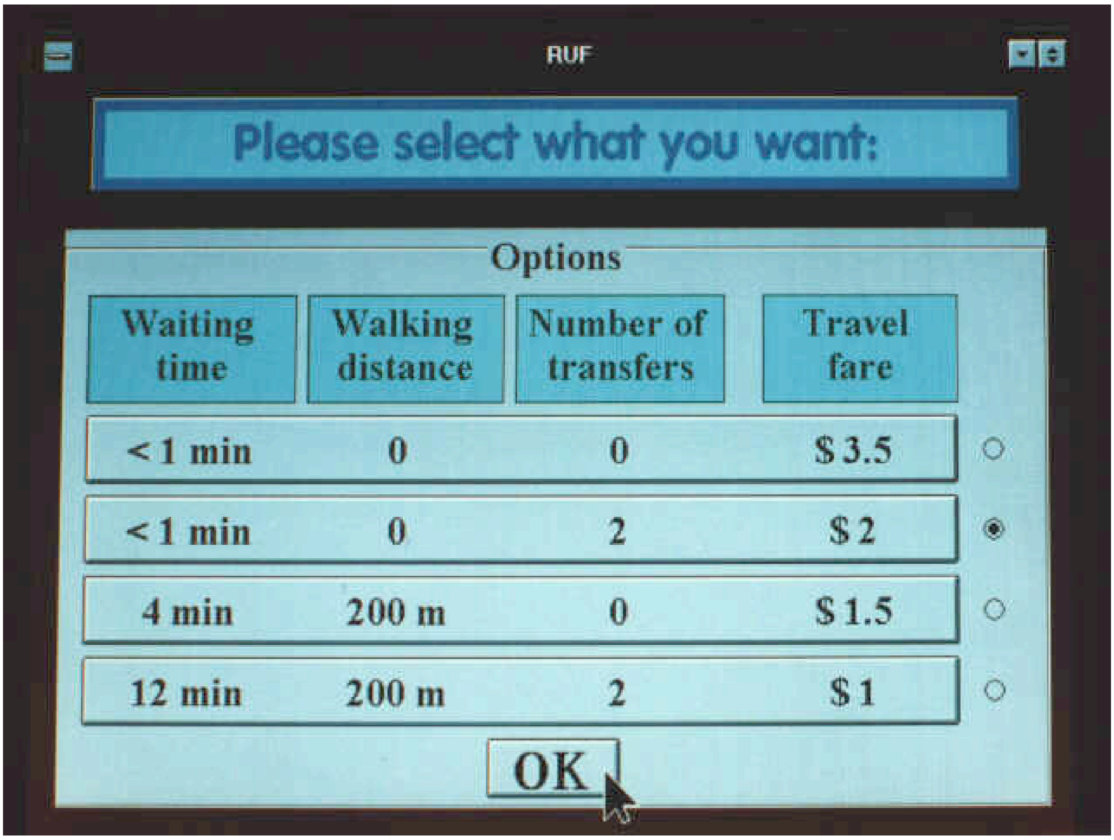


3) The maxi-ruf is organized in a way so that every passenger has his own seat. This means that the operator can allocate luxury seats to those who are willing to pay for it.

4) Vandalism can be avoided, since the operator knows who used the seat before a new passenger arrives. If the new passenger discovers that the seat has been damaged, the operator can find the responsible passenger. If nothing is wrong when a new passenger enter the seat, the information about the previous passenger is erased.



Use of the internet

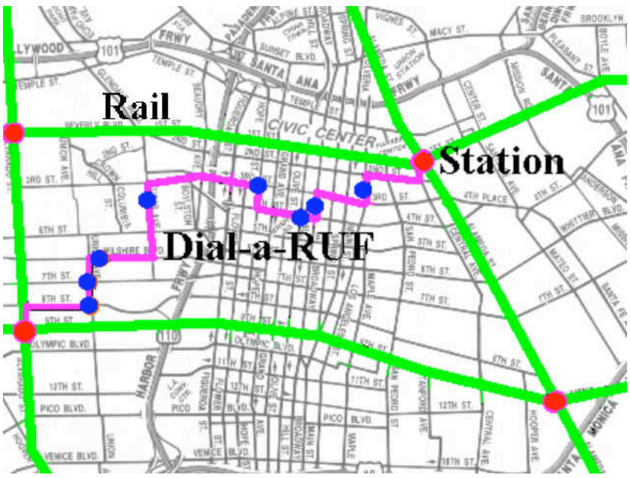


The internet can be used in order to select the level of service which you are willing to pay for. A selection screen could look like this:

You will have the option of being collected at your doorstep within a very short time and brought directly to your destination without transfer. It will be an expensive trip, but still cheaper than a taxi and you will have no parking problems when you arrive at your destination.

You will also be able to get a cheap trip if you accept to wait a little, walk to a pick-up place and transfer several times during the trip.

When you have chosen the level of service you want, you click OK and the operator plans the best way to deliver the promised service.



Other possible ways of communicating with the system includes special handheld devices with a screen just like a mobile phone:

The new Bluetooth protocol can be used to create small pocket devices without screen. They will make it possible to communicate with the system at special terminals acting as a “HotSpot” for the system. The device contains electronic money plus the often used destinations. When you get near (< 10 m) a HotSpot, you will be recognized by the system which responds with showing your initials. This means that you can see that you have been recognized but your identity has not been shown to others.

Physical interface

Public transport must be easy to use since it is needed by persons who are not so mobile as young people. In a traditional bus system the access is often very problematic for several reasons:

1) The driver is in a hurry because he has to comply with a time schedule.

2) The first step is often pretty high because the bus is large and it has to be able to pass over bumps in the road.
3) The passenger is not assured a seat when entering a bus. Standing in a bus can be dangerous when the chauffeur makes an unexpected braking.
4) The passenger needs to walk through the middle of the bus while the chauffeur accelerates the bus and turns to follow the traffic.

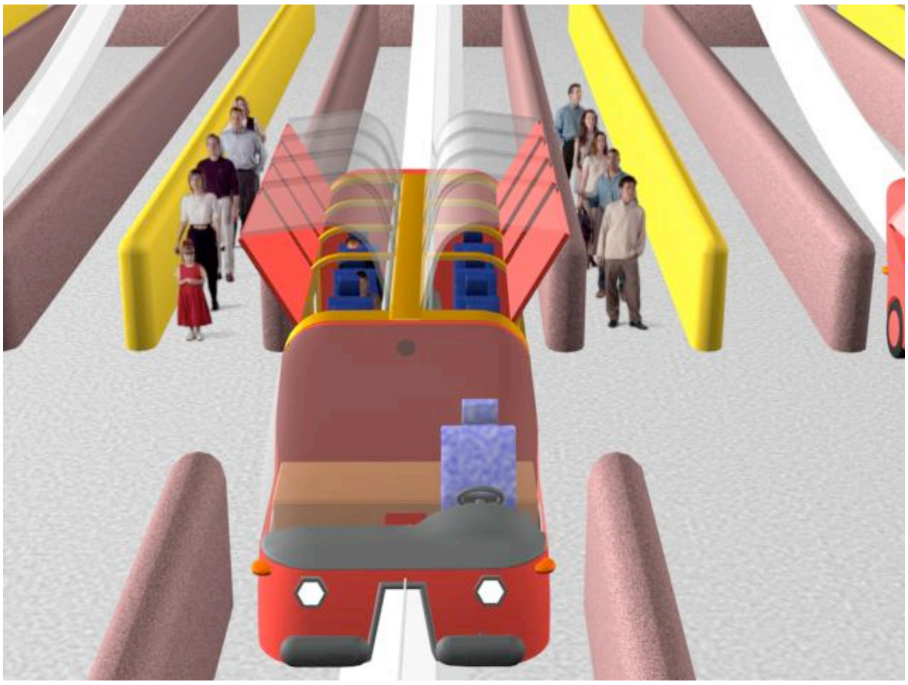
These poor qualities are some of the reasons why people often only use the bus when they have no alternative.

In the RUF system the quality is much higher for several reasons:

1) There is no time table, so the chauffeur is relaxed
2) The bus is small, so the floor is near to the ground
3) There are seats for everybody
4) The access to the seats is ideal
5) The bus is electric, so the acceleration is smooth.

In order to obtain these qualities, the bus is organized differently from normal busses.

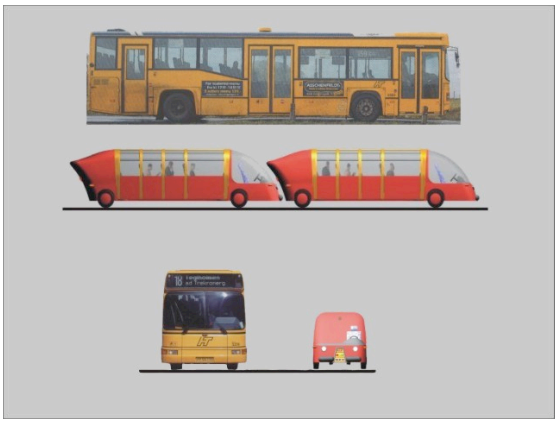
The fact that the maxi-ruf can "ride" on top of a triangular monorail means that the middle of the bus is occupied by a channel covering the monorail all the way along the bus. This makes it impossible to walk inside the bus. Consequently the passengers will have to find their seats directly from the street. This can only be done if every seat has directly access to the street.



This new principle of access is a major improvement for elderly people. It has a few drawbacks. Unlike a normal bus where the door always openes to the right side, the maxi-ruf will have to open to both sides. This is not a problem at stations, but in a busy street, some passengers may have to leave the maxi-ruf from the left side close to the other traffic.

The exit problem can be minimized in several ways:

1) The operator can organize the seats so that those passengers who are going to leave the maxi-ruf in a busy street, will get a seat in the right side. Those who leave the bus at a station or in a quiet street can be seated anywhere.
2) Since the maxi-ruf is much smaller than a normal bus, it can stop with an angle to the sidewalk, so that the rear will protect passengers who leave from the left side.



The special door is hinged at the top and folded in the middle so that it can be opened without interfering with the other doors. Any door can be opened at any time. When it is open, the access to the seat is ideal. The floor is low since the wheel separation is small and the door opening is as wide as possible. A simple device to open the door in 4 seconds has been designed and built on the 1:1 mock-up of the maxi-ruf.

Conclusion

New ways to improve the Human Machine Interface in public transport has been evaluated and a special door system has been built and tested successfully.

3.2.6 On-board interface (Robosoft)

Development and integration of on-board interfaces

3.2.6.1 Objectives

We want to validate a simplified Human Machine Interface for the RobuCab as a Cyber Transport System. On the control panel, A batteries level indicator, an emergency stop, a TouchScreen with a Graphical User Interface and a simple push button are used to control very easily the vehicle.

Fig 3.2.5.1 : The GUI menu on the touchscreen

3.2.6.2 Description

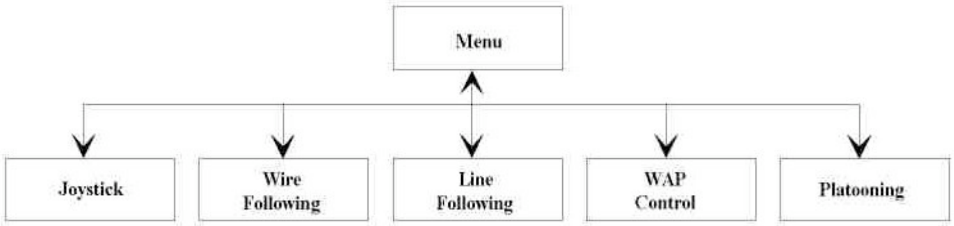


Fig 3.2.5.2 : The GUI allows the user to switch between modes

The TouchScreen is connected to the RobuCAB's computer by a serial link. An application written in Qt-embedded displays the Graphical User Interface and read the serial port to read the user's needs. The SynDEx application (Running on the MPC555 boards) gets the mode in the shared memory to choose what input to use to control the vehicle (Joystick, Wap, Plattoning…) and write the sensors values in an other shared memory in order the GUI to be able to display them on the screen.

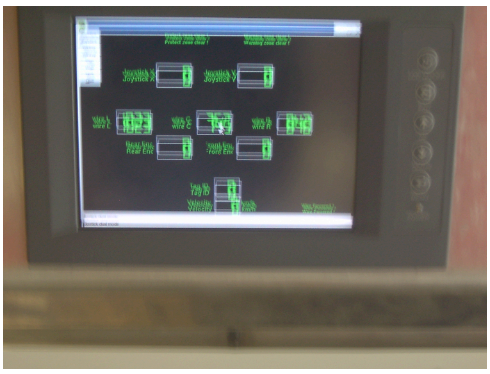


Fig 3.2.5.3 : Vehicle's parameters

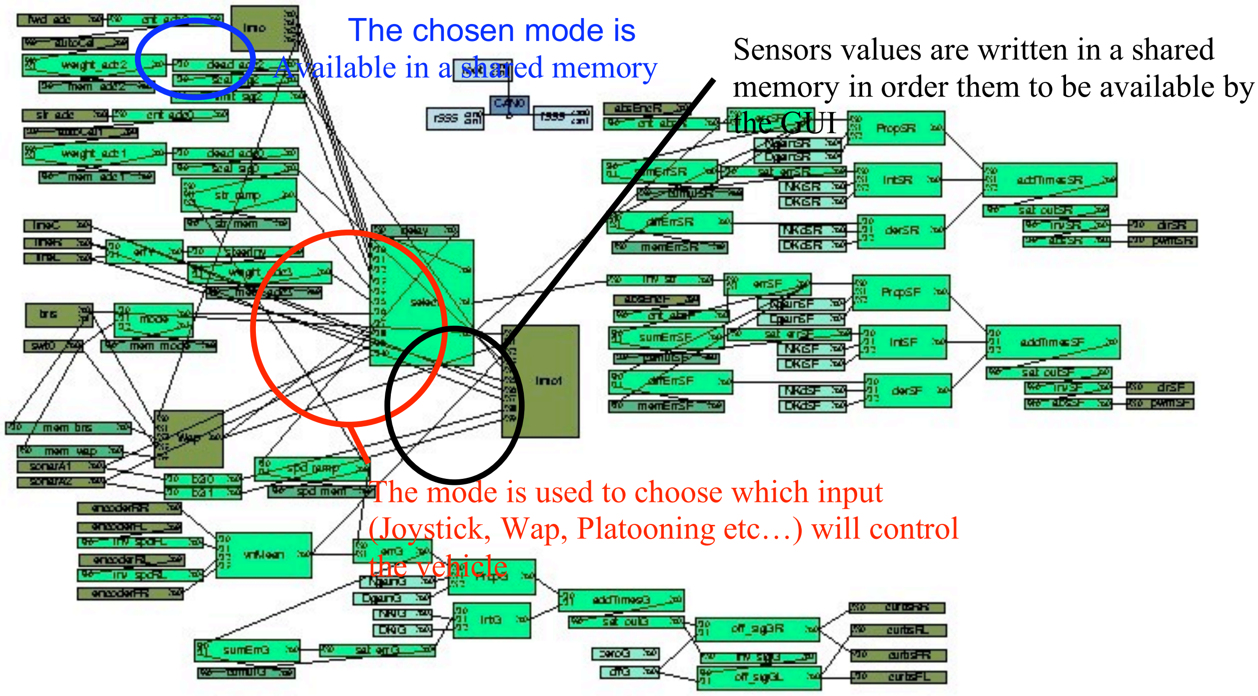


Fig 3.2.5.4 : The SynDEx application

Results

The GUI is both used to control easily the vehicle and to diagnostic it (reading the RobuCAB's parameters). The touch screen capability is available in Text mode but under development to be used with the GUI.

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3.2.7 On-board interface (SSA)

Development and integration of on-board interfaces

3.2.7.1 Description

3.2.7.1.1 Methods of payment

3.2.7.1.1.1 Small Change and Tokens

Roadside terminals and capsules are equipped with money boxes that accept change or pre-programmed tokens. During introduction of the first coin, the user is warned by an audio message that he has ten seconds to add more coins and to complete his payment. The payment is then recorded and the request is handled by the dispatching centre.

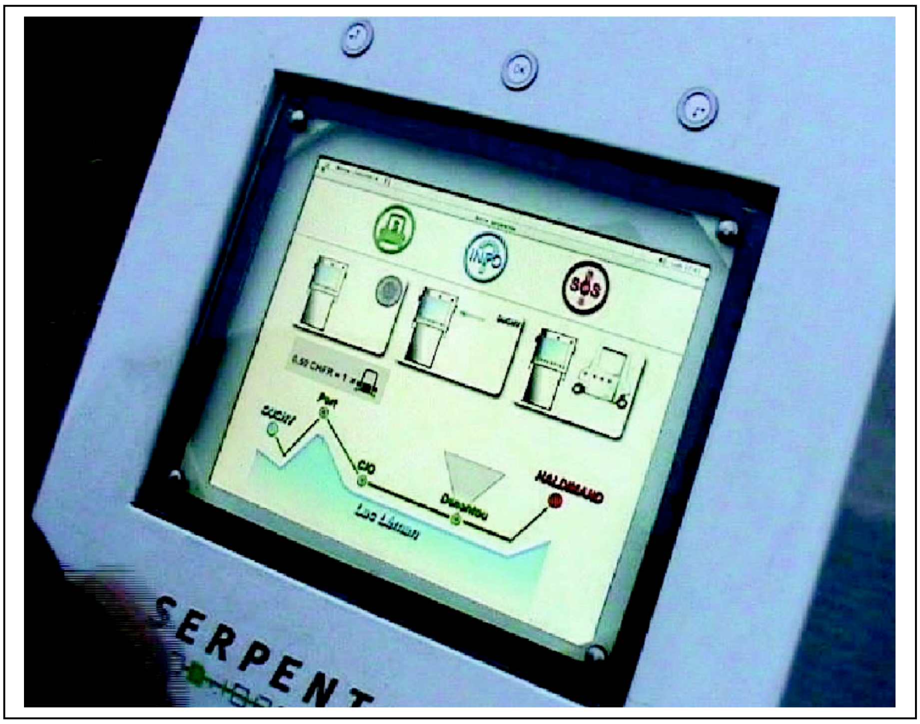
3.2.7.1.1.2 SMS (Short Message Service)

Any person owning an account duly registered with the operator of the Serpentine grid can call a capsule by an SMS from his mobile telephone. Once the validity of the message has been verified, the latter is sent to the dispatching centre and the amount is deducted from the user's account. Messages containing incomprehensible texts or coming from unidentified
persons are automatically rejected.

3.2.7.1.1.3 Magnetic Card

As a supplement to the two methods of payment described above, it is also possible to equip the roadside terminals and the capsules with magnetic card readers. In this case, two options exist for route selection, freely authorized for some identified persons or by debit on the magnetic card.

3.2.7.1.2 Information for the User



3.2.7.1.2.1 Roadside interactive terminal

Besides the possibility to order capsules, roadside terminals play an important role in the communication with the user. A straightforward navigation interface allows one to obtain many informations on capsule availability, or the map of the city grid and information on how to use the system. One could also consider showing the position of the capsules on the grid in real time.

3.2.7.1.2.2 In the Capsule

The Serpentine capsule is equipped with a system of audio information. If necessary, voice messages are received in a pre-selected language and according to the situation. One may also equip the capsules with a projector and project visual information against the windows of the capsule. It can be the same as that shown on the roadside terminal but can also be messages of informative character about the environment in which the route is going. For instance, during a tour of a factory, audiovisual explanations can be transmitted and synchronized with the progress of the visit. The same principle can be applied to a tour of a historic city core.

3.3 Remote operation

3.3.1 Control station (FROG)

3.3.1.1 Objective
Design of control station

3.3.1.2 Operational goal
.Develop a concept for remote operation of a cybercar system:
- vehicle requirements of remote operation
- system description for mobile/portable control system

Investigate control room consequences.

3.3.1.3 Deliverables
Concept description.

3.3.1.4 Description

3.3.1.4.1 Remote service and maintenance

In normal operation of Automatic Guided Vehicles for transport of people (CTS) will operate unattendanly. An operator is not needed in the daily routine. At the start of the operation an operator can do checks on vehicle and the site if everything is all-right. Also at the end of the day a check on vehicle can be made.
The operator is only needed in an alarming situation. In this case the operator has to be available immediately.
Immediately will mend:
- Direct view on the situation.
- Possibility to give instruction
- Personally present on site within 7 minutes (requirement from the customer).

With this views a remote operation can be done if the Supervisory system (SuperFROG is the supervisory system of FROG) will be extend with possibilities to communicate by a remote operator. Also the Supervisory system must have still the possibilities for normal operation. This in case the connections from the remote place will be not available.

With the remote operation the operational cost will be lower. An operator would not be available during the total operational time of the vehicles.

3.3.1.5 Description

3.3.1.5.1 Remote service and maintenance

An Automatic Guided Vehicles for transport of people (CTS) will operate without surveillance of an operator. An operator is not needed in the daily routine. At the start of the operation an operator can do checks for vehicle and for the site. Also at the end of the day a check for vehicle and site can be done. Only in an alarming situation the operator is needed. In this case the operator has to be available immediately.
Immediately will mend:

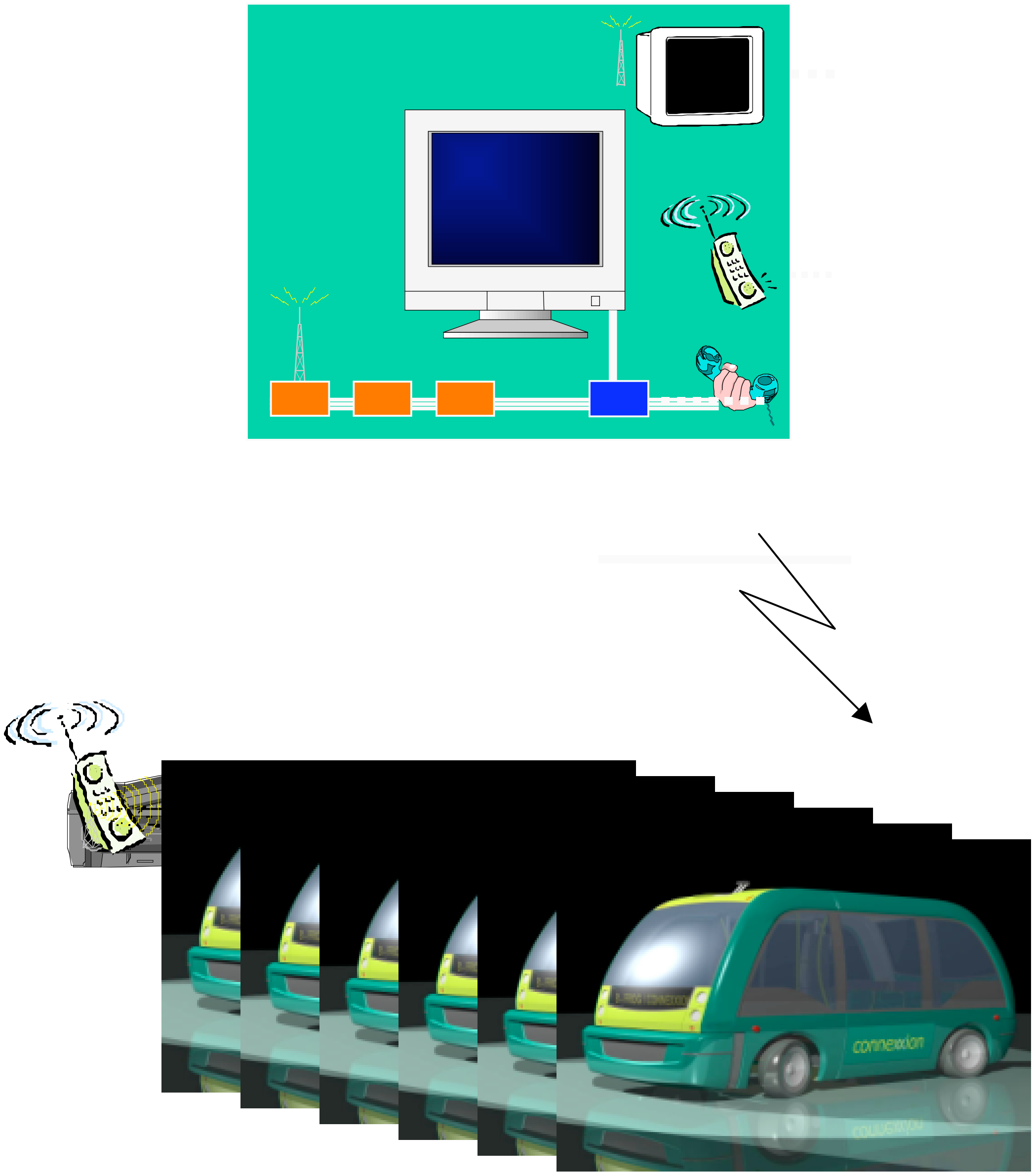
- Direct view on the situation.
- Possibility to give instruction
- Personally present on site within 7 minutes (requirement from the customer).

With this views a remote operation can be done if the Supervisory system (SuperFROG is the supervisory system of FROG) will be extend with possibilities to communicate to a remote operator. Also the Supervisory system must have still the possibilities for normal operation.

With the remote operation the operational cost will be lower. An operator would not be available during the total operational time of the vehicles. Infra structure can be changed; no physical place has to be available on the site. The operation can be combined with other duties.

3.3.1.5.1.1 System

The actual situation is shown in figure 1.



The local Supervisory System SuperFROG (SS) communicates with all the vehicles. The task of the SS is:

- Has overview of the system
- Knows the exact position of the vehicles.
- Knows the requests from the passengers

- Gives commands to the vehicles
- Frees sectors for vehicles

Via operator:
- Fills in the weather conditions
- Frees vehicles after emergency stop
- Manipulates vehicle to certain position (for initialization or out of operation)
- Can change the scenario of operation.

Operator has also the following possibilities:
- has an overview of the site via a camera system
- can react on malfunction of the system
- does daily maintenance work.

The SS communicates with the vehicles via a Wireless LAN (WLAN). Via this system the vehicle receives the commands form the SS. Also via the WLAN the vehicle sends status information (position, status) to the SS.
Also via the WLAN video can be send to the SS. In the vehicle two cameras are available. One is looking inside (overview of the passengers), one camera is looking affront of the vehicle.
On each vehicle the video pictures will be collected on a locale media. The registration is continuously. Herewith it is possible to have a history of at least 20 seconds.
Via a GSM connection a voice connection can be build up. Via the voice connection passengers and operator can be in contact with each other.
The SS is located on the site.

On the site 5 cameras are available for overlooking the situation. The video is available in the central station where also the SS is located. The cameras are located on safety critical places:
- Crossing
- Stations
- Bridge
- Overview in the garage
- Overview outside the garage.

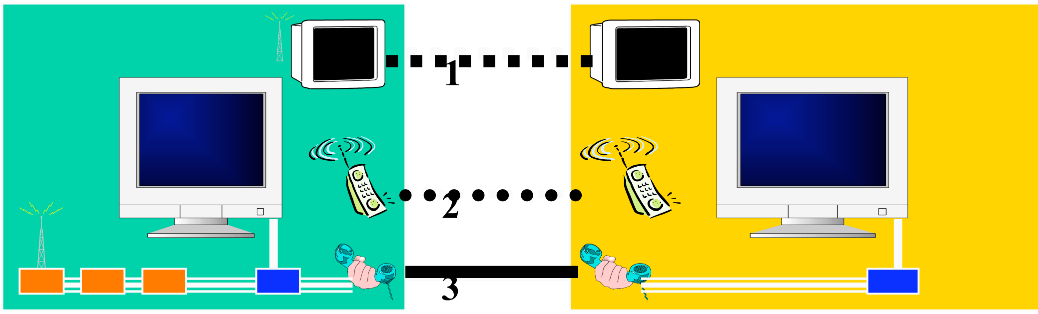
(Vehicles will be located in the garage outside the operational hours. During these hours the batteries will be charged).

3.3.1.5.1.2 Remote system

The remote system (RS) will be located on the central place of the Public Transport company. In this place various operators are located to have control over the Public Transport system. To operate (control) the CTS will be one of their tasks. In emergency situation the operator can call a “local” service operator. Latter on the implementation can be extended where also the “local” service operator have information via a handheld and can do the first-line support on distance. For this implementation the results of the other partners will be used.

Communication of the RS.

In figure 2 an overview is given of the situation.



The RS is almost a copy of the SS.
The RS will communicate via the SS to the vehicles. All control of the vehicle will still done by the SS. The RS can give a subset of commands to the vehicle (via SS). Also the status information will be available on the RS.

Communication SS and RS

For communication between the SS and the RS the following requirements has to be met:

- Communication based on IP connection (is a system-requirement of SuperFROG (SS))
- Communication has to be continuously; data and commands have to be sending directly in time.
- Burglary into the system has to be very difficult
- The minimal transmission capacity has to be 128 kbit/s
- Disconnection of the communication has to be less than 0.5 second

With the start-up of the connection based on the IP connection a login/password verification will be done. All data of the SS will be stored on the SS.
With the start of the remote operation the connection between SS and RS will be done with a 128 kbit/s digistream straight connection. With this choose the connection is reliable.

Beside the digistream connection a connection will be tested via internet. Advantage of this connection is the low operational costs. Research has to be made for the availability of internet and the influence on the commands and status information. Safety of the system has to have the highest priority. In all situations commands and information have to be given.

Communication of voice

The voice connection between the vehicles and the SS will be setup via a GSM connection. For the communication with the RS the same GSM connection will be used. In the vehicle a special GSM module will be used. The passenger has only to push a button and the connection will be made automatically. In case of remote operation the connection will be automatically done to the remote operation site.
The “locale” service operator can make contact directly via the GSM to the vehicle for given also instructions.

Communication of the video
The video of the cameras on site are connected to the system via a glass fibre. The operator can manipulate the computer for picture-select and zoom function.
The video from the vehicle goes via WLAN. The video is on demand available on the SS. The video will be available on low rate transmission. (1-2 picture/second) (the communication between SS and vehicle control is more important and use also the WLAN as communication medium).

Video can be send via the digistreaam connection (see connection SS and RS). To have a reasonable connection the digistreem connection has to be expanding to 256 kbit/s.
Also in this case the connection via internet is an option.

3.3.1.5.1.3 Consequences for operation

Start-up of the system.
In principle the system can be start-up automatically. The vehicles will be leaving the garage automatically.
With normal operation the operator has an overview over the garage. For the remote operation an additional camera will be placed to have an overview of the garage. The Remote operator will taken attention during the start-up procedure via the cameras. It is recommended to make a test-drive with one vehicle over the site. The remote operator can examine the site. After this test-drive the other vehicles can leave the garage and can be positioning to the places.

End of day routine.
The vehicle will be places automatically in the garage. During the night the vehicles will be charged. For charging pads will be operated automatically. Indication of charging is available on the SS. Opening and closing the garage-door will be under control of the SS.
For remote operating the control will be done via the available cameras.

It is un-acceptable that persons will be lock-up during the night. Therefore the following measures have to be taken:

- The garage door can be open from inside manually.
- The vehicle voice communication will be function all over time. In this case a passenger can make contact to the central post. The central post can open the connection to a particular vehicle.
- In the vehicle a sensor will be place to indicate the present of people.
- With a camera inside the garage the present of people can be notified.

Operational servicing
Weather conditions
For operations the weather conditions has to fill in. If weather conditions are changed the operator can change the weather input for the system. This is a safety issue. If there is snow on the track the weather-

condition can be filled in. The system will lower the maximum speed of the vehicles. Several measures can be taken on the weather conditions.

With remote operation there is no direct relationship with the place of the operator and the situation of the track. Therefore the operator will be asked to confirm the weather-conditions on regular basis. The weather-conditions (rain. temperature, wind) on the track will be measured by a local automatic weather-station which is connected to the SS. Also with the cameras the conditions of the track can be observe.

Maintenance
The following maintenance tasks are in the daily routine:
Button test (emergency).
Normally this test will be done once a week by a locale operator. The system will check if this test is done and reports this to the SS. If the test is not fulfilled within 2 weeks a warning (phase-1 indication) will be given. After 3 weeks the system will not start-up (phase-2 indication).

Cleaning the obstacle-sensor.
The obstacle-detection sensor has a build-in test for detection of the cleanness of the sensor. With this information a warning (phase-1) or phase-2 situation can be given.

Cleaning door-sensor of the vehicle.
If the door-sensor is dirty the sensor will signal a permanent obstacle between the doors. With the on-board camera of the vehicle the remote operator can see the actual situation and make appropriate measures.

Battery liquid condition
The liquid condition of the batteries is measured. A phase-1 or phase-2 condition will be generated.

Heating liquid condition
The fuel condition of the heating is measured. A phase-1 or phase-2 condition will be generated.

Malfunction.
All malfunction reports which are communicated with the SS are also available in the RS.
The remote operator can take the appropriated measures.

Malfunction of a station.
The operator can close the station. The system will still operate with exception of the malfunction station. The “local” operator will be informed.

Malfunction of the barrier
If the barrier is closed for the public traffic the “local” operator will be informed. System will be function. Vehicles can trespass the barrier.
If the barrier remains open for the public traffic the SS will not free the section for the vehicle and the vehicle will stops for the trespassed. The “local” operator will be informed.

Malfunction of the vehicle
Obstacle detected.
If the obstacle disappears the vehicle will follow the route. If the obstacle remains the remote operator can switch to the vehicle camera and also to the wall-camera for an overview of the situation on the track. The remote operator can communicate via voice to the passengers. The remote operator can take the appropriated measures.

If the vehicle stops the remote operator can maneuver the vehicle via “limb home (see later)” procedure to a particularly place and inform the “local” operator.

With other malfunction of the vehicle the “local” operator has to be informed.

Releasing a fault-situation is a normal procedure. In this procedure different security issues has to be fulfilled before the system can be released. This can be done also remote. Visual check via the cameras is part of the procedure.

Limb-home procedure
In special situation a limb-home action is allowed:
The operator gets a “malfunction” situation and can make the situation visible on the screen via the video pictures. He can choose the “limb-home” status for placing the vehicle on a particular spot where the vehicle will not disturb the operation. Latter on the vehicle can be checked by an local operator. Within the “limb home” status the operator has to make a visual check via the cameras. He has to fill in a “pin code” for doing the “limb-home” maneuver. Then he can control the vehicle. Status will be available on the screen. The maximum speed of the vehicle will be reduced to 1 m/s. The section where the vehicle is will be closed for other vehicles. The vehicle can be send to particular places. Passengers can leave the vehicle on these places.
The “local” operator will be informed.

3.3.1.5.2 Conclusion

With the remote operation control over the system can be done in a safe way. The remote operator has the availability for overlooking the situation and takes care of appropriate measures. Also the passengers can be informed directly.
For special cases a “limb home” procedure can be carried out, in which situation the normal operation will not disturbed.
The remote operation will be cost effective. Also the quality of work will be improved: people need not do dull work.

3.3.2 On-board controls and image acquisition (robosoft)

3.3.2.1 Objectives

Provide Automatic transport of people over various type of sites (industial sites, parks, museums, universities,...) user with a telephony (GSM/GPRS) compliant HMI for interacting with the transport application.

Fig 3.3.3.1 : A wap phone using the system

3.3.2.2 Description

The vehicle is following a path and, using a Wap phone, everybody can order a vehicle to stop at the desired station. A server is getting Wap data and send them to the vehicles.

Wap data are download from the Wap site by a server. Then they are send to the robot using a wireless ethernet. A client application written in C language in the RobuCAB's computer collect the requested stops (Station1, Station 2 …) and send them to the SynDEx application (Running on the MPC555 boards) throw a shared memory. When the vehicle is crossing a tag, it compare its number to the stop requests and stops the vehicle if needed.

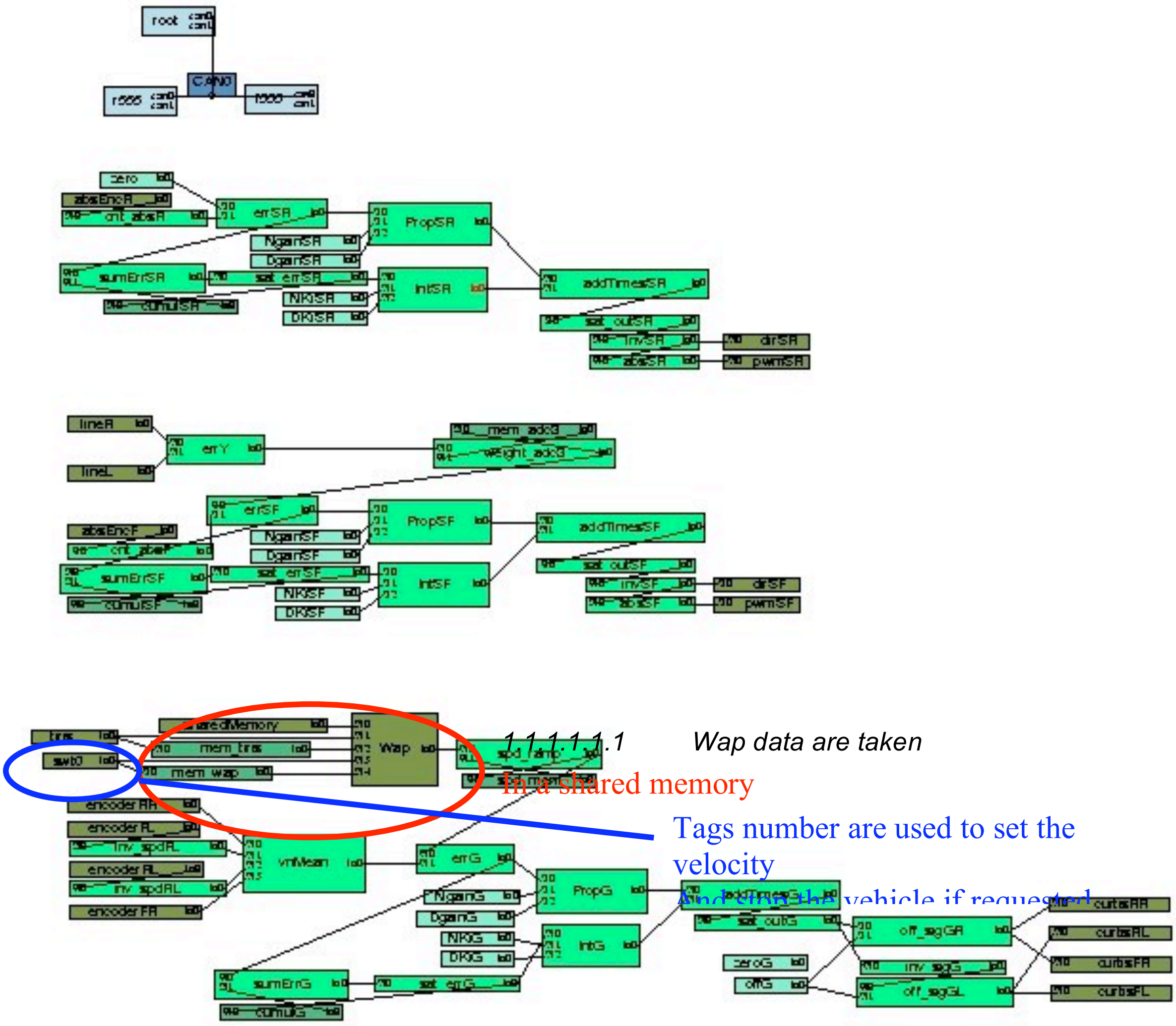


Fig 3.3.3.2 : The SynDEx application

3.3.2.3 Results

The response time is 3s minimum depending on the network charge.
We planed to develop i-mode sites and web pages for smartPhonet or pocketPC. We want to export the acquisition of the WebCam installed in the RobuCab on Web sites and be able to display it on a mobile phone.

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3.4 Energy management

3.4.1 Recharging strategies (INRIA)

Installation and test of automatic recharging stations. Development of software for optimum recharging strategies

3.4.1.1 Objective

- To develop a simulation software for testing optimal recharging strategies for cybercars and the management of the recharging stations in an efficient way

3.4.1.2 Operational goal

- Develop a simulation model for evaluating the optimal recharge level for Cybercars.
- Develop management rules for the optimal recharging of cybercars at the recharging stations.
- Develop and implement the software for optimum recharging strategies
- Test and evaluate the performances

3.4.1.3 Baseline reference

- The balancing method and recharging system used in Praxitele projects

3.4.1.4 Deliverables

Simulation Model, Optimisation techniques, Recharging Management software, Performance evaluations

3.4.1.5 Description Recharge of automated electic cars

3.4.1.5.1 Problem setting

The problem considered in this paper consists in analyzing a control policy based on two parameters: (i) the so-called threshold, which is the charge level of the battery with regard to which the decision is made to send the car to the recharging station, and (ii) the recharge level, which is the level of the charge of the battery at which the car is released from the recharging station, and thus is made available to customers.

The threshold is denoted by TH and the recharge level by RL. Indeed, TH<RL. The objective is to define TH and RL so as to reach a service ratio closed to one using as few electric cars as possible.

In this paper, we assume that the recharging station is unique. We also assume that the recharging function, that is the function that provides the recharging time in terms of the recharge level, is an increasing and concave function. We refer to this function as the recharging function.

When a customer calls for an electric car in order to go to a given destination, the system selects a car among the cars that are:

- not busy,
- not in the recharging station or on the way to the recharging station.

The selected car is the one that will use the minimum energy to join the customer and take him / her to his / her destination. Since energy consumption is proportional to the distance covered, this means that we select the car that is the closest to the departure location of the customer.

Thus, three different distances should be considered in this problem, that is:

- the distance from the selected car to the departure location of the customer; we denote this distance by X,
- the distance from the departure location to the destination of the customer; we denote this distance by Y,
- The distance from the customer destination to the recharging station; we denote this distance by Z. Distance Z is of importance only if the recharge level is less than TH when the customer is at destination: in this case, the car is sent to the recharging station.

During a trip, the following situations are possible:

- The car arrives safely at destination, and the recharge level at this point is greater than TH. In this case, the car remains at this position and becomes available for another customer. This case is denoted by C1.
- The car arrives safely at destination, but the recharge level at this point is less than or equal to TH. The car is moved towards the recharging station. If the car arrives safely to the station, we say that we are in case C2.
- The car arrives safely at destination, but the recharge level at This point is less than or equal to TH. The car is moved towards the recharging station. If energy is not sufficient to reach the station, we say that we are in case C3.
- The energy is not sufficient to reach the departure location of the customer and to take him / her to destination. This case is referred to as C4.

We developed simulation software in order to evaluate the performances of the system. The assumption made in this software and some additional information are given in the next section.

3.4.1.5.2 Assumptions

The simulation software proposed in this paper is based on the following assumptions:

- X, Y and Z, which are defined in the previous section, are random variables. Their probability densities are known. Note that these random variables are considered as being independent from each other. This approximation increases the generality of the software since these three variables can be analysed independently from the environment. Their definition is issued from a statistical analysis based on data collected *in situ*.
- In case C3, the car runs out of energy on its way to the recharging station. We consider that, whatever the point where the car stops, we will need the same duration to transport the car to the station. We denote this time by T3.
- In case C4, the car runs out of energy either on its way to the departure location of the customer or between the departure location and the destination. We consider that, whatever the point where the car stops, we will need the same duration to transport the car to the station. We denote this time by T4. Indeed, T4 > T3.
- A service is said to be efficient if an electric car is available immediately when a customer require it.
- A customer requirement that is not satisfied immediately is lost and will never be satisfied.

Let us describe the simulation software.

3.4.1.5.3 The simulation software

The input data are the following:

- The maximal charge of an electric car, denoted by CM.
- The distance D the car can cover with the charge CM.
- The probability rules of random variables X, Y and Z.

- The elementary period DEL. This period is the clock of the simulation: the state of the system is computed at each instant k * DEL for k = 1, 2, 3,.. Note that DEL is as small as possible but the smaller DEL, the slower the simulation.
- The threshold TH.
- The recharge level RL.
- The speed of the cars, which is supposed to be constant.
- The recharging function denoted by f'(x), which represent the time required to bring the charge at level x from level 0. The properties of this function have been presented in the first section.
- The number NN of simulation steps. Thus, the duration of the simulation is TT = NN * DEL.
- The probability p that a customer's requirement appears during one elementary period. Note that the elementary period is small enough so as to include at most one customer requirement.
- The number of cars in the system.

The outputs of the simulation are:

- The total number NR of requirements during period TT.
- The number of cases C3 during period TT. We denote this number by NC3.
- The number of cases C4 during period TT. We denote this number by NC4.
- The total running time of the recharging station during period TT. We denote this time by TRC.
- The ratio of the number of efficient services by the number of requirement. This ratio is defined as:
  $RES = (NR - NC3 - NC4 - NFL) / NR$
  where NFL is the number of time no car was available when a requirement appeared.
- The ratio of the total running time of the recharging station by TT:
  $RRT = TRC / TT$.

The algorithm can be summarized as follows:

1. Initialisation.
   This first step of the algorithm consists of introducing the input data that have been described above and assigning the value 0 to NR, NC3, NC4 and TRC.
2. For i=1 to NN do
   2.1 Generate $W \in \{0,1\}$ where:
   $$W = \begin{cases} 1 \text{ if a customer's requirement appears} \\ 0 \text{ otherwise} \end{cases}$$
   2.2 If W=1, generate X and Y at random. Then select, among the cars that are available and whose charge is greater than TH, the car that will need the lowest energy to take the customer to his / her destination and compute the charge of this car at destination. Increase NR by 1.
      2.2.1 If the charge of the car at destination is greater than 0, compute the time required to reach the destination and assign this time to the car. This time is called the transportation time of the car. This time is less than or equal to 0 when the car is available.
      2.2.2 If the charge of the car at destination is less than or equal to 0, assign the time T4 to this car, increase the index of case C4, that is NC4, by one and assign the car to the set of cars on their way to the recharging station.
   2.3 Selection of the cars whose state changes.
      2.3.1 If a car arrives at destination, then:
         - If its charge is greater than TH, the car becomes available.

- Otherwise, generate Z at random. Then, two cases are possible: (i) the energy is sufficient to reach the recharging station; in this case, compute the time required to reach this station (travel time) and assign the car to the set of cars on their way to the recharging station, or (ii) otherwise, assign the time T3 (travel time) to this car and assign the car to the set of cars on their way to the recharging station. Increase also the index of case C3, that is NC3, by one.

2.3.2 If the recharging station is idle, or if the recharging time of the car under recharge is less than or equal to 0, then select, among the set of cars that are on their way to the station, the first in the queue whose travel time is less than or equal to zero. If such a car exists, let CC its charge. Assign this car to the recharging station with the recharge time $RTI = f(RL) - f(CC)$. Increase TRC by RTI. The car that left the station becomes available.

2.4 Next step: subtract DEL to all the times (recharge time, travel time to the station or time associated to the customer service). Replace all the negative times by 0.

A numerical example is given in the next section.

3.4.1.5.4 A numerical example

The numerical example presented hereafter has the following input data:
CM = 20
D = 35
X,Y and Z are uniformly distributed between 0 and 5.
DEL = 0.1.
TH = 3.
RL takes the values 4, 8, 12, 16, 20.
The speed of the cars is 1.
$f(x) = 1.1 * (1 - \exp(-x/2))$
NN = 30,000
p=0.05.

Figure 1 provides the percentage of efficient services as a function of the recharge level for different number of cars in the system.

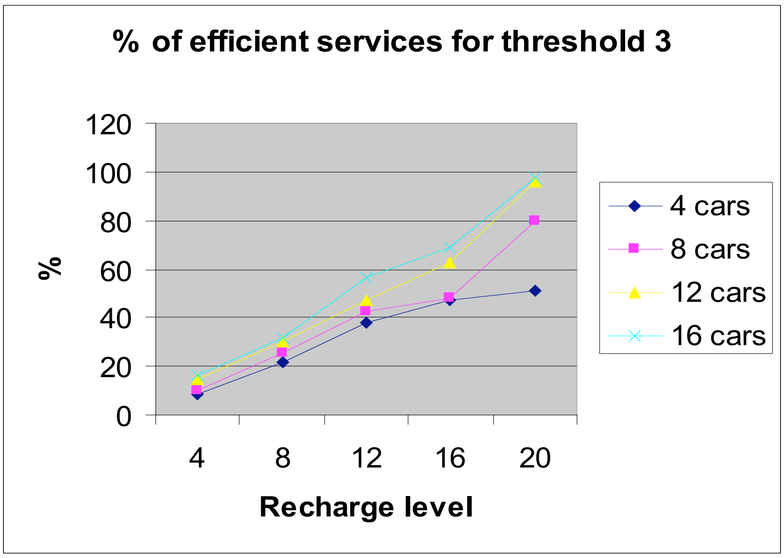


Figure 1: Percentage of efficient services versus recharge level.

The percentage of efficient services increases with the recharge level whatever the number of cars in the system. This is due to the fact that the number of useless trips to the recharging station decreases as the recharge level increases.
We also observe that the percentage of efficient services increases with the number of cars. This is due to the fact that the greater the number of cars, the larger the choice of cars, and the bigger the opportunity to find a car close to a customer when needed.
In figure 2, we give the percentage of time dedicated to recharge with regard to the recharge level for different number of cars in the system. This percentage decreases as the recharge level increases: this is due to the fact that the number of useless trips to the recharging station decreases as the recharge level increases. Also, the tendency is to observe an increase of this percentage when the number of car increases for the bigger recharge level. This is a consequence of the fact that the charge of all the cars is kept at the higher possible level.

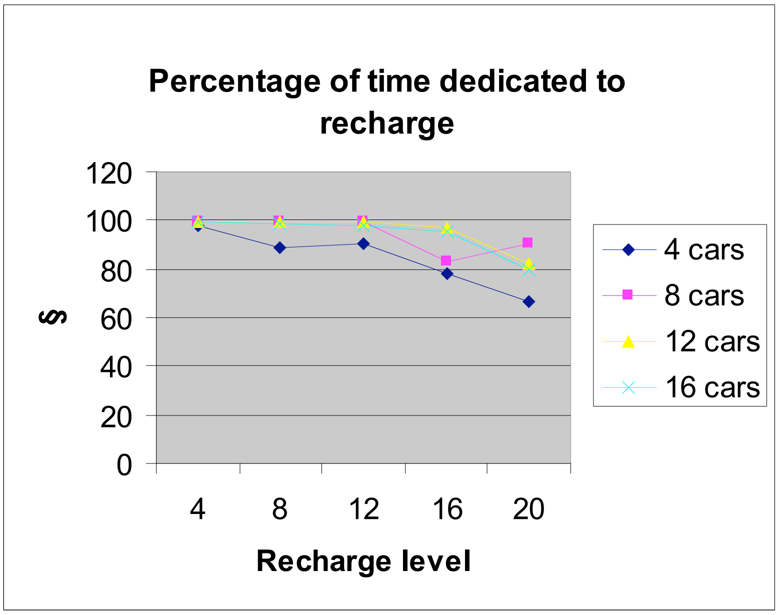


Figure 2: Percentage of recharging time versus recharge level

3.4.1.6 Conclusion

The policy based on the threshold and the recharge level is very efficient in steady state.

3.4.2 *Automatic energy transfer system (A&E)*

Develop and realise a prototype of an automatic energy transfer system. During the testing and validation, A&E will produce statistics and analyses of the charging of the batteries

3.4.2.1 Objectives

- Recharge automatically the on-board batteries of the cybercars, without human intervention, being compatible with the environnement, substructures, types of vehicle.

- Realise a precise inventory of accumulators and super capacitors available in the market, evaluate them and make a smart choice also considering the financial balance.

- Create un system of recharging, where the used techniques are compatible with the different cybercars being developed, allowing quick transfers of energy (rapid recharging) to shorten the immobilization time of a cybercar during its exploitation time.

- Develop a technique of order and control being adjustable to the needs of the administrator, including several types of recharging curves adapted to different types of accumulators.

- To adjust a computerized battery management compatible with all kinds of accumulators.

3.4.2.2 Operational goal

- Evaluation of the world offer in the field of batteries.
- Evaluation of the European offer in the field of chargers, on board or stationary.
- Evaluation of the bases of battery management system.
- Development of a prototype of automatic recharging arm.
- Development of a recharging station.
- Test of the system
- Evaluation.

3.4.2.3 Baseline reference

Battery management Mentzer/Badicheq
For recharging station and arm, nothing is presently existing. Robot arms exist for liquid fuel (see Robosft).

3.4.2.4 Deliverables

- Curves for batteries analysis
- Vehicle equipped with a prototype of automatic recharging arm

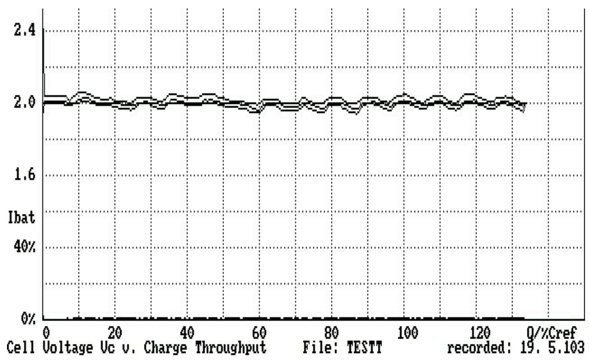
- Prototype of recharging station
- CD presentation

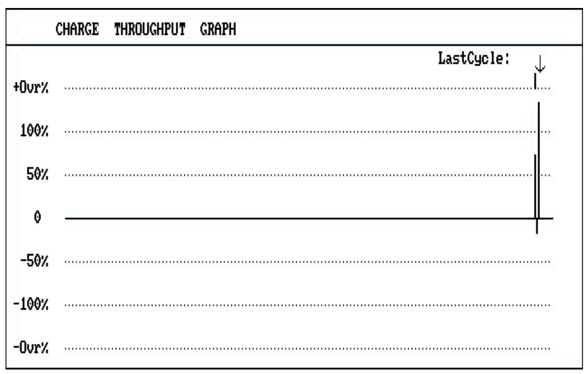
3.4.2.5 Description

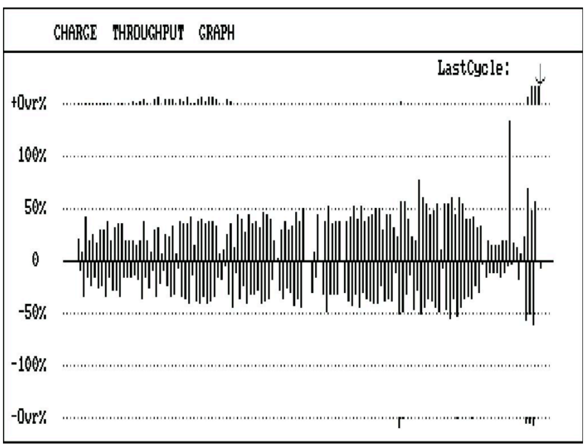
1. The evaluation of the offer of batteries and super capacitors has shown couples as Nickel metal hydride – Li-ion – Zinc-air – Nickel-Zinc and Pb. Pb battery without maintenance was chosen because of the low exploitation costs.

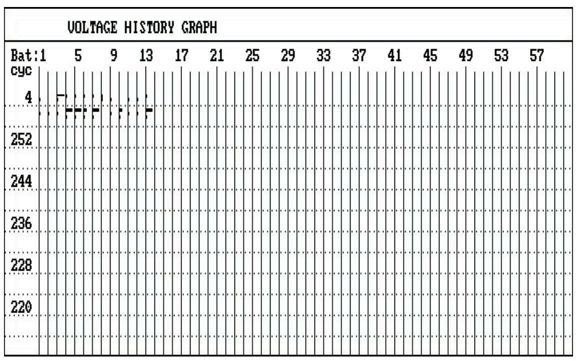
2. The actual offer for on board charger high frequency is very interesting. The recharging curves can be adjusted to any type of batteries thanks to micro processors.

3. We were able to organize the battery management in adapting an existing program. By these means we followed the behavior of the battery placed in the cybercars.









The cybercar is coming near the charging station

3.4.2.6

The realization of the recharging station was done considering functional, security and cost criteria. The station gives entire satisfaction. A design study is on its way.

A recharging station is placed on the side of the lane in the chosen area. It also has an area of contacts without potential and a light signal, lighted when connection is made. This recharging station is constantly connected to the electric grid, but will only deliver the energy when the contacts of the arm are connected to its own contacts.

When the transfer of energy is over, the arm will automatically be removed from the recharging pole and the Cybercar can go on its way.

The recharging station

3.4.2.7 Conclusions

The tests realised with the automatic recharging arm and its connexion station have shown the important advantages of such a system. The computerized following through of the on board battery gives us a precise look of the evolution of the battery.

The evaluation already shows :
- the various possibilities of this automatic system of recharging
- its reliability
- the saving times

3.4.3 Continuous charging (SSA)

Analysis of advantages of continuous charging through the infrastructure
The Magnetoslider®, Serpentine's energy transmission without contact system

3.4.3.1 Objectives

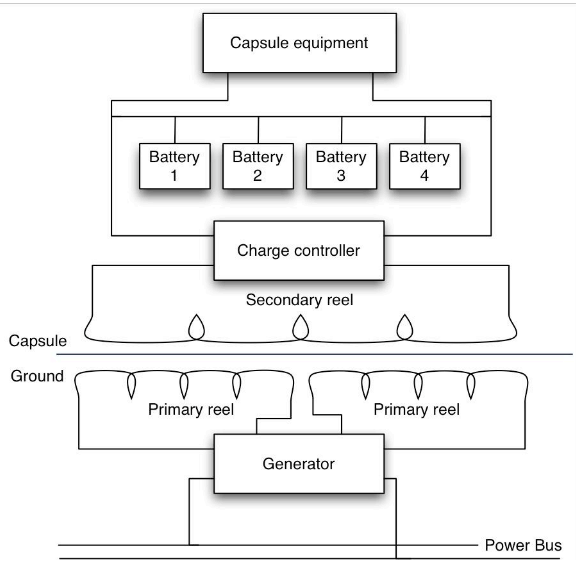
The Serpentine transport system relies on energy transmission without contact and thus patented continous charging of the on-board batteries for several objectives :

- The capsule does not need wait times for charging.
- It decrease the overall weight of the capsule as it does only need four classic automobile batteries as buffer. The power consumption is then also decreased.
- The magnetic field is used for positioning laterally and longitudinally the capsules on the track at any time, permitting automatic guidance and overall network management.

The maximum power need of a Serpentine capsule is around 2,5 kW in very hard conditions (10% slope with 5 persons on board). In average conditions (no slope, 10 km/h speed and two persons), the global energy consumption of a riding capsule is about 600 W.

3.4.3.2 Functional principle

The functional principle of the energy transmission is shown in the following schema:



The generator produces an electric tension with a very high frequency (above 80kHz) in the primary reel which produces a magnetic field.

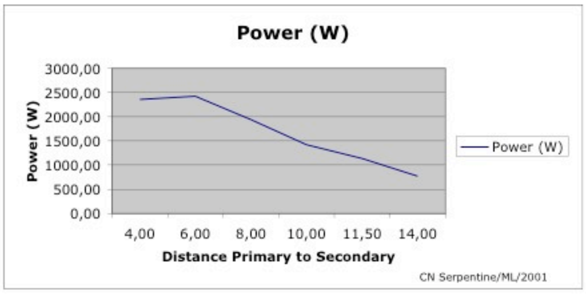
The magnetic field creates a tension and a power in the secondary reel fixed under the capsule. The charge controller tunes statically the frequencies, transforms the power from AC to DC and stabilize the tension to around 50 Volts.

There is three main characteristics to be aware in designing the system of energy transmission without contact : Frequency of the current, distance between primary and secondary reel, primary reel voltage.

3.4.3.3 Laboratory results

Before mounting this charging system on Serpentine vehicles, development was done in laboratory to prove the feasability and choose the best components for real conditions.

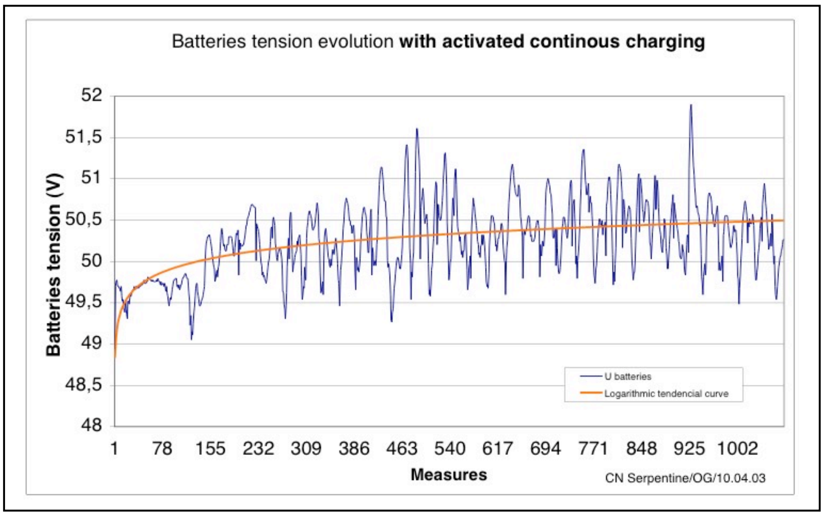
Distance primary to secondary (cm)	Primary reel			Secondary reel			Output
	Current (A)	Tension (V)	Power (W)	Current (A)	Tension (V)	Power (W)	
4,00	10,87	251,00	2728,37	4,67	504,00	2353,68	86,27%
6,00	11,38	250,00	2845,00	4,75	510,00	2422,50	85,15%
8,00	8,77	250,60	2197,76	4,27	454,00	1938,58	88,21%
10,00	6,70	250,60	1679,02	3,71	383,30	1422,04	84,69%
11,50	5,45	251,50	1370,68	3,32	341,80	1134,78	82,79%
14,00	3,96	250,80	993,17	2,77	278,20	770,61	77,59%

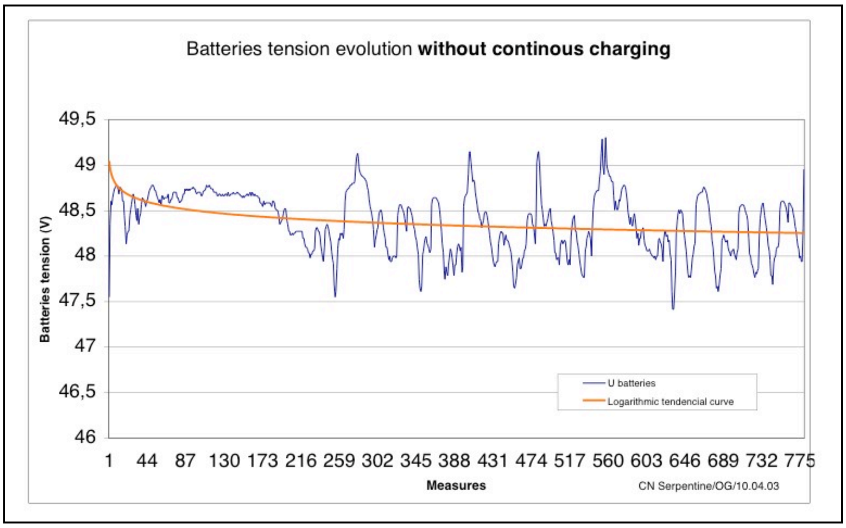


The above table shows results of measurements in laboratory with a static system. It may be noticed that the best output is found when the primary reel is at 8 cm away from the secondary reel and the highest power transmitted is above 2.4 kW.

3.4.3.4 On site results

All kind of measures are systematically logged as the Serpentine capsules rides to control the overall evoluting characteristics of the system. In particular, the two recent following graphics show the evolution of the batteries tension during a portion of a ride.





The conditions of these measurements shown above are the following :

- Distance beween primary and secondary reels : 10 cm
- Vehicle speed : 6 km/h
- Same track

The above two graphs show clearly that the power transmitted is largely sufficient to cover the capsules needs in normal conditions.

In a dynamic system, the functioning of the continous charging is slightly more complex as it needs synchronization between track and vehicle. As the Serpentine capsule moves along the track, only the two primary reels under the capsule are producing a magentic field to avoid electrical smog (passengers are protected against it with an aluminium sheet). The Magnetoslider® patented system ensures that the secondary reel always receive power from two primary reels which frequencies are exactly the same and synchronized, so that no difference between the two primary reels makes the transmission totally unstable.

3.4.4 Charging procedures (UB)

Modelling and simulation of charging procedures

3.4.4.1 Description

This report presents work on the development of simple Battery models which may be used to model the charging process for a battery powered Cybercar.

In many cases, there are opportunities to recharge Cybercar vehicles during their use. An important element of determining optimum use is therefore to develop good battery management approaches.

The literature appears to concentrate on discharge models for batteries and has little readily available information on charging models. The present work is based on analysis of an extensive series of tests carried out under the ULTra program on the discharging and recharging of lead acid batteries. This data has been analysed to provide an insight into key parameters affecting the process.

It was found that the process was extremely complex. Nevertheless a series of battery charging models have been developed. These are based on empirical analysis of the data available. It is believed that these will be valuable for first order evaluation of the charging process in battery driven Cybercars.

3.4.4.1.1 Introduction

Effective use of Electric Vehicles requires development of effective approaches to recharging their batteries. Surprisingly there appear to be no battery charging models readily available in the literature. Reference books such as Berndt (1997) offer extended models for battery discharge but provide little data about battery charging.

The same comment appears to apply to the leading battery modelling programs eg Advisor (available from the US DOE). It seems certain that there must be suitable models available in the literature, but reasonably extended search has failed to identify these.

One reason for this may be that battery recharging is normally undertaken over an extended period at modest charging levels, typically overnight. For Cybercarsthere is often the opportunity to recharge more frequently. For this the relative benefits of various battery charging management approaches need to be evaluated using a simulation model. It seems likely that a comparatively simple model reflecting the key parameters of the process could provide sufficient accuracy to permit judgements on optimum battery management approaches to be made.

The ULTra project has available results from extended tests on battery charging and discharging undertaken by CMP on their Orbital battery. This data was taken against a specific ULTra related duty cycle and therefore only covers a very limited usage scenario. However, the data is particularly complete and can be used to identify key aspects of a suitable model. This data has been used to develop an empirical model of the batteries so that battery behaviour under alternative discharge conditions could be observed and to allow exploration of alternative recharge techniques.

This report concerns the development of a computer-based battery model for the battery discharge process. The following sections of the report explain lead-acid battery technology, focusing on valve-regulated types with absorbent glass mats, as that is the type used in the tests. A brief overview of current battery models is given in section 3, together with an explanation as to why the chosen method was used in this case. An explanation of the tests conducted and the formatting of the results for import into Matlab is given in section 4, together with preliminary data analysis. Finally, the method used to develop the model is explained and the model presented. There is considerable room for improvements and this is outlined in the conclusion.

3.4.4.1.2 Lead Acid Batteries

This section is heavily based upon the book 'Maintenance-Free Batteries' by D. Berndt.

3.4.4.1.2.1 Overview

A lead acid battery consists of a number of cells in series to give the desired nominal voltage output, as a single cell can only produce approximately 2 Volts. The basic principle of a lead-acid cell is shown in figure 1 and explained below.

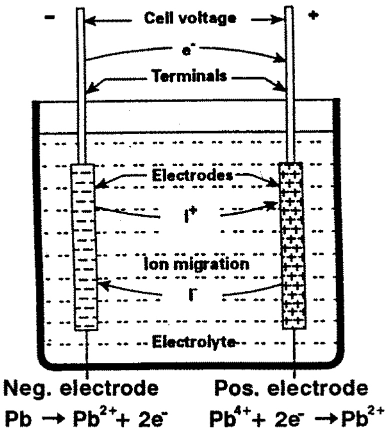


Figure 3 - A Lead-Acid Cell

Rechargeable cells operate by converting chemical energy into electrical energy during discharge, and vice versa during charging. The capacity and voltage of a cell is therefore dependant upon the chemicals used and their quantities. In the case of lead-acid technology, a single cell consists of a container, two electrodes made from lead and lead dioxide, and an electrolyte consisting of sulphuric acid and water. Figure 1 shows the basic charge transfer reactions that occur at each electrode during the discharge process. Together, these form part of the single chemical cell reaction that takes place during discharge, namely:

$$Pb + PbO_2 + 2H_2SO_4 => 2PbSO_4 + 2H_2O \qquad \text{Equation 1}$$

During recharge, the same reaction occurs, but in reverse.

The first lead-acid cells to be developed required vents to allow hydrogen to escape, resulting in loss of water* that needed to be replenished on a regular basis. Modern lead-acid batteries are available in the so-called 'maintenance free' variety, which is a sealed package. These packages contain a valve to allow

* Hydrogen generation and water loss is explained in more detail in the following sections.

hydrogen to escape from the cells when the pressure has become too great. The valves also inevitably allow water to escape at the same time, but the batteries still have a service lifetime of up to ten years.

3.4.4.1.2.2 Equilibrium Voltage

The equilibrium voltage of a cell, denoted by E^0, is equal in value to the cell's open circuit voltage (i.e. the voltage across the cell terminals when no current is flowing). As the name suggests, E^0 refers to a condition where all chemical reactions occurring in the cell are balanced. Its value is governed by the laws of thermodynamics, specifically, the free enthalpy of the cell reaction, denoted ΔG.
As ΔG depends upon the concentration of the reacting components, E^0 is a function of the concentration of the acid used in the cell. A concentration of 1.01 g/cm^3 results in an E^0 of 1.828 V, whilst a concentration of 1.39 g/cm^3 gives E^0 equal to 2.241 V. Typically, acid concentrations in the region of 1.14 g/cm^3 are used, resulting in an E^0 of 2.000 volts.
E^0 is also affected by temperature, although the temperature coefficient is so small that its influence can usually be neglected.
As previously stated, the equilibrium potential is equal in value to the cell's open circuit voltage. However, the open-circuit voltage is usually not, strictly speaking, an equilibrium voltage but actually consists of a 'mixed potential', whereby two separate reactions occur at an electrode, and their effects cancel each other out.

3.4.4.1.2.3 Capacity

3.4.4.1.2.3.1 Definitions

Battery capacity, referring to the total amount of energy that the battery can deliver, is defined and quoted in two different forms.

Firstly, there is the watt-hour definition:

$$C_{Wh} = \int_0^t E(t)I(t)dt \qquad \textit{Equation 2}$$

More commonly used is the amp-hour definition:

$$C_{Ah} = \int_0^t I(t)dt \qquad \textit{Equation 3}$$

When quoting the capacity of a battery in amp-hours, it is necessary to complement it with indications concerning the voltage. Commonly accepted parameters are:

- **Starting/initial discharge voltage**: This corresponds to the cell voltage at the moment the load is applied. For lead-acid cells, this is usually defined as the voltage after 10% of the capacity has been discharged. This is in order to avoid a voltage anomaly at the beginning of discharge, referred to as the 'coup de fouet'.
- **End-of-discharge/final voltage**: This corresponds to the voltage of the battery once the battery is considered to be empty. This should be defined by the manufacturer, and discharge beyond this point is referred to as 'deep discharge', which should be avoided. End of discharge voltages tend to decrease with increasing discharge rates.
- **Average discharge voltage**: This is the average of the cell voltage over the duration of the discharge, so that average discharge voltage x current = discharged energy.

3.4.4.1.2.3.2 Factors Affecting Capacity

As one might expect, the capacity of a cell is heavily dependant upon its design, but it is also influenced by environmental factors such as the rate of discharge and temperature.

Higher discharge currents result in lower available capacities, and also lower starting and final voltages. As a consequence of this, capacities for different discharge rates are usually quoted by the manufacturer, with C_{10} and C_5 for example denoting the available capacities with 10 hour and 5 hour discharge rates respectively.
The influence of temperature on available capacities is more pronounced at high discharge currents, with higher capacities available with temperatures above room temperature, and lower capacities available with lower temperatures.

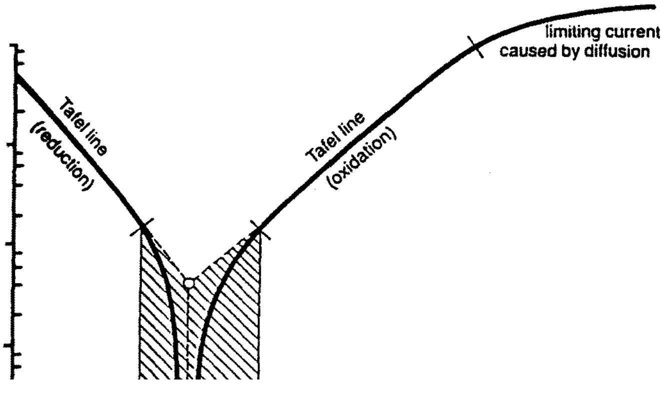
3.4.4.1.2.3.3 Deep Discharge and Service Life

Deep discharge of a cell occurs when it is discharged beyond the 'end-of-discharge voltage' quoted by the manufacturer. Whilst a cell can easily survive a deep discharge, if this is repeated often, permanent changes in the active material of the cell occur; capacity and service life are reduced as a result. It is therefore advisable to avoid repeated deep discharges.

Whilst the service lifetime of a cell depends upon its design, it is largely determined by the cell's operating conditions. The end of a cell's service life is usually defined as the point at which only 80% of the cell's original capacity remains at full charge. In some applications, life expectancy is quoted in calendar time, whilst in others it is quoted as the number of charge-discharge cycles. Ageing occurs both with time and with charge-discharge cycles, and is heavily affected by the operating temperature. As a general rule, each rise of 10° C in the cell's operating environment will halve the cell's lifetime.

3.4.4.1.2.4 Current Flow

When current flows, the cell reaction must take place at a corresponding rate. In order to achieve the current flow, a deviation from the equilibrium potential is required in order to provide the necessary additional energy.
During discharge, the cell voltage decreases and in order to recharge the cell, the voltage must be increased beyond the equilibrium voltage. The change in voltage observed is due both to the additional energy required to obtain current flow, and voltage drops due to the resistance of the current carrying parts of the cell.
The rate at which current can flow is determined not only by the characteristics of the charge-transfer step (as shown in figure 1), but also by the characteristic of any steps in the cell reaction that occur before or after this step. In the case of lead-acid cells, the reactants that take part in the charge-transfer must diffuse across a layer of lead-sulphate on the electrodes first. This can limit the maximum rate of current flow, particularly during the recharge process.
When the current flow is not limited by the diffusion rate, the current-voltage relationship is determined by the 'activation energy', which represents an energy barrier that electrons must overcome during the charge-transfer reaction.
At voltages close to E^0, this relationship is complex, but with voltages further from E^0, it becomes a simple exponential one. The relationship is referred to as the 'TAFEL equation', as J. Tafel was the first to describe it. Figure 2 shows a current-voltage curve for a typical cell.



During recharge, as the cell voltage is increased, the current will increase until the concentration of reactants at the charge-transfer site falls to zero. At this point, the current becomes limited by the speed of diffusion, which cannot be influenced by voltage. The current now depends solely upon the concentration gradient of the reactants and the width of the layer across which they must diffuse. The cell voltage at which this limiting current is observed, together with the current's magnitude, falls as the cell nears full charge, since the concentration of reactants in the recharge reaction diminishes to zero.

As a result of this limiting current, the recharge duration can only be slightly reduced by an increased recharge voltage, whilst a number of disadvantages occur. It is therefore advisable only to use an increased recharge voltage at the beginning of recharge for a short period of time.

3.4.4.1.3 Electrolyte In More Detail

The lead-acid cell electrolyte is dilute sulphuric acid. As indicated in section 2.1, sulphuric acid is involved in the cell reaction. During discharge, the acid concentration is reduced, and increased again during recharge. As a result, the equilibrium voltage decreases with remaining capacity, as does the acid conductivity.

3.4.4.1.3.1 Freezing Point

When a cell is at full capacity, the freezing point of the contained acid is around –50°C. However, when a cell is deeply discharged and the acid concentration considerably reduced, the freezing point is increased to around –8°C. Whilst the cell will still operate in this condition, the internal resistance is considerably increased and recharging especially is hindered. Although the freezing of the electrolyte does not usually destroy the cell, it can have a detrimental and permanent affect upon it, and as a result it is advisable to keep discharge levels low at very low operating temperatures.

3.4.4.1.3.2 Stratification

The changes in electrolyte concentration during discharge and recharge can lead to stratification, whereby the acid concentration is significantly different in various locations of the cell. However, with valve-regulated lead-acid cells, the electrolyte must be immobilised in order to facilitate the internal oxygen cycle. A useful by-product of this process is that acid stratification is considerably reduced.

3.4.4.1.3.3 Immobilisation

In the case of the batteries being considered by this report, immobilisation is achieved through the use of an absorbent glass mat separator, placed between the cell electrodes. The mats consist of fine glass fibres that absorb the electrolyte by capillary forces. Such glass mats thereby immobilise the electrolyte and also act as a conventional electrode separator, preventing the growth of lead dendrites which would otherwise cause short circuits.

3.4.4.1.4 Loss of Water

Water loss in valve-regulated lead-acid cells is of interest as it cannot be compensated for by re-filling, and is a major cause of capacity decrease in these designs. Water loss can take place in two different ways:

- Permeation of vapour through container walls.
- Electrolytic decomposition and escape of gaseous hydrogen or oxygen.

3.4.4.1.4.1 Permeation Of Vapour Through Container

Plastic material usually used for cell casings are permeable to water vapour to some extent, and water can therefore be lost from the electrolyte by diffusion into the surrounding atmosphere. In normal European atmospheric conditions however, the moderate humidity usually means that water loss by this mechanism is minimal.

3.4.4.1.4.2 2.6.2 Electrolytic Decomposition

Decomposition is the split-up of water into hydrogen and oxygen according to:

$$H_2O \Rightarrow H_2 + {}^1/_2O_2 \qquad \text{Equation 4}$$

This reaction occurs in the cell whenever the cell voltage is equal to or greater than 1.229 volts.
Nearly all of the hydrogen that is evolved by this reaction escapes from the cell when the pressure is great enough and the valve opens. Hydrogen evolution accounts for a water loss in the order of 7% over 10 years.
Most of the oxygen produced by this reaction is reduced again at the negative electrode, forming the internal oxygen cycle, and some is consumed in the corrosion of the positive electrode. Any remaining oxygen escapes with the hydrogen when the valve opens.
The factors affecting the rate of water loss are complex. Several different reactions and parameters influence the rate at which the decomposition must take place, but overall water loss is influenced by temperature and the state of charge of the battery.

3.4.4.1.5 The Internal Oxygen Cycle

The internal oxygen cycle was mentioned briefly in the previous section. It concerns the generation of oxygen at the positive electrode, and its subsequent reduction at the negative electrode. Together with hydrogen evolution and positive electrode corrosion, the internal oxygen cycle is referred to as a secondary reaction, since it is not part of the cell charge/discharge reaction.
When the cell is discharging, or it is recharging and has not yet reached a full state of charge, the rate of the internal oxygen cycle is negligible. However, when the battery is fully charged and a recharge current is maintained (this is referred to as float charging), only the secondary reactions remain and the internal oxygen cycle dominates. A high efficiency of the cycle is important to help minimise water loss from the cell.
In order for oxygen generated at the positive electrode to be reduced at the negative electrode, it must diffuse in the gaseous state (as diffusion in the dissolved state is too slow) across the cell. The electrolyte immobilisation mentioned in section 2.5.3 allows for this diffusion. As the cycle depends upon concentration gradients of oxygen, its rate is not significantly affected by cell voltage or temperature.

3.4.4.1.6 Heat Effects

Heating of a cell takes place through two different mechanisms; the reversible heat effect and the Joule effect.
The reversible heat effect represents the unavoidable heat emission or heat absorption connected with electrochemical reactions. It is directly related to the thermodynamic parameters of the concerned reaction and to the amount of material that takes part in the reaction. The amount of heat concerned with this effect is therefore independent of battery design and varies only with current.

The Joule effect concerns heat generation due to current flow. Any current will cause energy loss in the form of heat, proportional to the voltage drop caused by the current flow:
Where ΔV is the voltage drop due to the current I, and Q is the energy, in Joules, lost as heat.

$$\frac{dQ}{dt} = \Delta V \bullet I \qquad \text{Equation 5}$$

Any heat generated in the cell causes its temperature to increase until the rate of heat generation is equal to the rate of heat dissipation into the surrounding environment.

3.4.4.1.6.1 Heat Generation During Discharge

During discharge, the reversible heat effect contributes a cooling factor, but this is usually masked by the much higher Joule effect (which always contributes heat). At low discharge rates, e.g. 20 hours, the reversible heat effect is greater than the Joule affect and the cell cools down.
However, the Joule effect quickly increases with current, so at higher discharge rates this dominates and the temperature of the cell will rise accordingly.
During discharge, the voltage drop due to current flow is given by $E^0 - V$, where V is the cell voltage, therefore the energy loss due to the Joule effect is given by:

$$\frac{dQ}{dt} = (E^0 - V) \bullet I \qquad \text{Equation 6}$$

3.4.4.1.6.2 2.8.2 Heat Generation During Charge

During charge, there is an additional heat generation that can be attributed to the secondary reactions. Also, the reversible heat effect causes a loss in energy as opposed to the gain it contributes during discharge.
When the cell's state of charge is low, heat generated during charge is caused by the reversible heat effect and the Joule effect. As the cell reaches maximum charge, the secondary reactions begin to dominate, reducing the reversible heat effect to zero and minimising the Joule effect. In this situation, the rate of the internal oxygen cycle determines the heat generation.

3.4.4.2 Overview Of Different Model Types

There are three different types of modelling approach used in the field of batteries; equivalent circuit models, electro-chemical models, and purely empirical models. Clearly, there are many models currently in existence, it is both unnecessary and impossible to cover them all individually here.

Some models are developed to focus upon one particular area of battery performance, for example, detailed electrochemical models of the internal oxygen cycle are available, but are of no use in determining a battery's discharge performance. As a general rule, electrochemical models tend to be more specific than other types, as attempting to develop such a model to cover all battery conditions and uses would take a considerable period of time. Determining all of the parameters for such a model would be exceptionally complex, resulting in a model that is highly specific to the battery upon which it is based.

The most common and general models are equivalent circuit types. The simplest and least accurate is a model consisting of a fixed voltage source in series with a fixed internal resistance. Such a model is useless as a serious development tool. Much more complex models have been developed, incorporating more circuit elements, and/or modelling the value of the circuit elements as functions of battery parameters such as state of charge. These models can then be fit to specific batteries using empirical techniques to determine various function coefficients or circuit element values. Some equivalent circuit models are coupled with a thermal model of the battery, providing a comprehensive model overall.

An interesting method of fitting circuit element values is to use Electrochemical Impedance Spectroscopy (EIS). This method involves testing the battery's internal complex impedance over a range of frequencies, and fitting the model's impedance spectrum to the results.

Lastly, purely empirical models have been developed using neural network techniques, but clearly these models are only as good as the data upon which they are based and inherently specific to the battery that is tested.

In this case, it was decided to use a purely empirical model. This would allow for a quick initial development time and the possibility of extending the model with more detail in the future if necessary. An electrochemical model was avoided due to the high complexity, long development time and lack of suitable data from which to derive the required parameters. An equivalent circuit model was avoided due to a lack of time and difficulty with deriving the required parameters from the data available.

3.4.4.3 Conclusions

The results from testing the models indicate that they provide a reasonable fit to the data. However, there is considerable room for improvement in these models whilst maintaining their simple empirical basis.

Firstly, for each model type, there is a separate model for 2.3, 2.35 and 2.4 V/Cell recharge voltage. It should be a relatively straight forward matter to incorporate each of these separate models into one through the use of 2-D look-up tables, but there was insufficient time available to do this at this stage.

Secondly, there is the much more challenging task of incorporating temperature effects into the model. This is a two stage process. Battery heating effects including heat generation and dissipation need to be modelled so that the temperature of the battery can be accurately predicted. This temperature value then needs to be used to affect the other values in the model, such as current flowing or charge accepted in a one minute charge period. Neither of these tasks are trivial, and will require considerable time to complete.

Thirdly, no account of battery ageing is currently made in the model, as sufficient data is not available. If further test were conducted, it may be possible to include aging in a straight forward manner.

Finally, the models would be more reliable if they were based upon true state of charge data rather than accumulative amp hours, as some of the energy input during recharge is not stored in the battery, but contributes heat or is absorbed by the secondary reactions of the battery. This would require extensive new tests to be run on the batteries.

Having made these additions, the empirical models would be at their limit. However, there would still be shortcomings. It is highly inadvisable to use empirical models such as these for circumstances which are outside the data upon which the models are based. For example, these models would be useless for analysis of alternative float-charging techniques, as they do not model secondary reactions in any way. Also, the range of values of state of charge across which the models are accurate decreases with increasing recharge voltage (due to the data upon which they are based).

It is therefore recommended that the modelling process should be taken a step further, with an equivalent circuit based model. Such a model should provide more accurate results upon which design decisions, concerning all aspects of battery operation, can be reliably based. This would be easiest to achieve with new and more suitable test data from the batteries, from which the necessary parameters and component values can be derived. The data that is currently available could then be used to verify the accuracy of such a model.

3.4.5 Energy management: measurements, processing & analysis Measurements (TRI)

3.4.5.1 Simulation Model - Description

A theoretical model was developed for evaluation of the performance of cyber-cars equipped, in the general case, by one battery or by two: the main battery with large energy density, and an auxiliary with large power density and regeneration braking capability. The model is intended for optimization of the battery module and of power train parameters. It includes the relations between the electrical motor efficiency and load factor, and between the batteries efficiencies and depths of discharge (DOD) for driving and regenerative braking (RB) operation (the RB – for the motor and the auxiliary battery only). These analytical relations were obtained in this work; their form and the set of needed parameters are based on published literature data, and on measurements performed in this and previous Technion works. The model also employs known equations of mechanics and an expression to account heat losses in the electrical circuit. The latter relation involves the load factor as an independent variable, and was based on the known electro-dynamic relations. The model does not presuppose using large data files for efficiencies: of the vehicle motor, η_{mot}, of the transmission, η_{tr}, of the inverter, η_i and of battery, η_{bat}, for driving and RB operation conditions of the engine. The model uses empirical equations for the vehicle motor and battery efficiencies obtained in the work and is based on the following assumptions:

a) Transmission efficiencies: $\eta_{tr.dr}$, $\eta_{tr.reg}$, under driving and RB operation conditions, respectively, and that of the inverter: $\eta_{i.dr}$, $\eta_{i.reg}$ - are taken as mean values.
b) For transient operation regimes, the mean total RB efficiency, as well as the mean total of the reciprocal value of the driving efficiency, were calculated under the assumption that they are functions of the load factor, $p_{load} = p_{tr} / p_{tr.max}$, at DOD = const (here: p_{tr} - traction power, $p_{tr.max}$ - maximal traction power). The power in this case will be approximately proportional to the vehicle speed at small values of the aerodynamic resistance (larger than the acceleration force together with climbing and rolling forces). The latter case is not typical for electric vehicles.
c) An effective ohmic load resistance approximation is used in the calculations of heat losses in the vehicle electrical circuit. The mechanics equations with the corresponding empirical parameters are taken from the handbook [8] and from [9]. The latter is used to account for the effect of the wind direction on the aerodynamic drag coefficient.
d) The route of a vehicle is divided into segments, such that on each segment the vehicle speed and/or acceleration and the road gradient are constant.

The dependencies of the motor drive and regenerative efficiencies on P_{load} are proposed in the following form:

$$\eta_{mot}(P_{load}) = \eta_{mot}^{0}(P_{load}) * \eta_{heat}(P_{load}) \quad (1)$$

Here $\eta^0_{mot.dr}(P_{load})$ and $\eta^0_{mot.reg}(P_{load})$ are preliminary motor efficiencies, without taking into account heat losses.
The fact that the regenerating efficiencies of the electric propulsion system components are less than that in driving operation, see [9,11,12], is used in deciding on a regeneration efficiency value in cases of lack of the data.
Total driving & RB efficiencies, and the corresponding energy consumption, E_{cons} ,and RB energy, E_{reg} , are expressed the following known equations:

$$\eta_{tot.dr} = \eta_{mot.dr} \times \eta_{tr.dr} \times \eta_{i.dr} \times \eta_{bat.dr} \quad (2a)$$

$$\eta_{tot.reg} = \eta_{mot.reg} \times \eta_{tr.reg} \times \eta_{i.reg} \times \eta_{bat.reg} \quad (2b)$$

$$E_{cons} = (P_{dr} / \eta_{tot.dr}) \times t \quad (2c)$$

$$E_{reg} = P_{dr} \times \eta_{tot.reg} \times t \quad (2d)$$

Here t is time, $\eta_{mot.dr}$ is given in eq. (1); $\eta_{tr.dr}$ is the transmission driving efficiency; $\eta_{i.dr}$ is the inverter driving efficiency; $\eta_{bat.dr}$ is the battery driving efficiency and similarly for the regenerating braking case; the heat losses factor, η_{heat} , is substituted in these equations according to eq. (1).

Equations for the calculations of the climbing and rolling resistance forces, and the acceleration force, with the corresponding empirical coefficients, are taken from [8].
This set of mechanics equations enables the calculation of the acceleration, climbing, rolling and aerodynamic drag resistance forces. These are needed for the computation of the drive and regeneration braking power and the consumed and saved energies which are inverse and directly proportional to the corresponding total efficiencies of the electric vehicle propulsion system. The total efficiencies are products of the battery block, motor, inverter and traction efficiencies. The mean values of the latter two are given in the input file; the previous two efficiencies are calculated according to the algorithm, which is presented in the previous sections.

The flowchart in Figure 1 illustrates the model's algorithm, as described above.

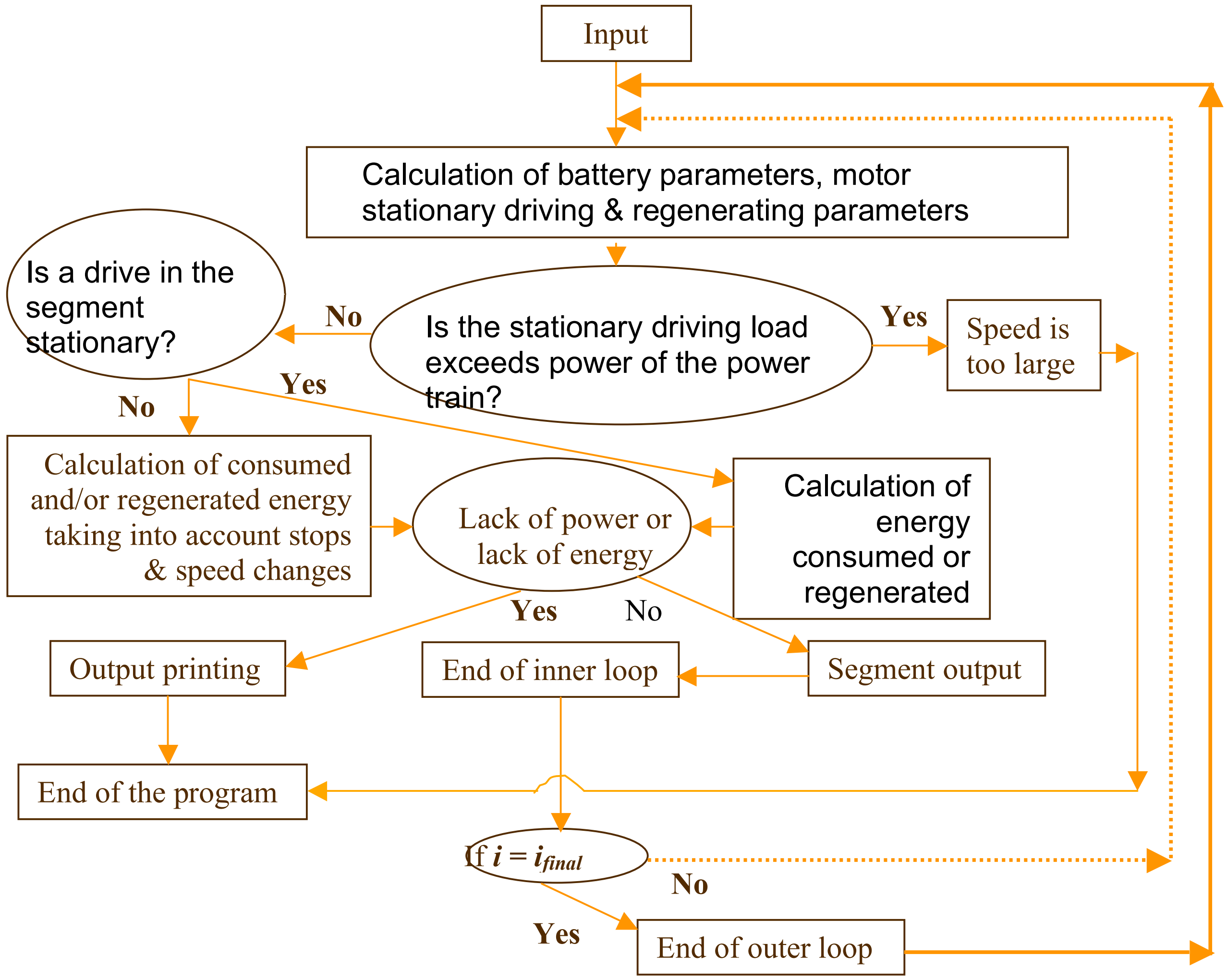


Figure 1. Flowchart of the model's algorithm.

3.4.5.2 First simulation results

Initial simulations using the model developed were carried out based on the experimental data supplied by INRIA. The driving cycle used as the basic (reference) one in the calculations was the cycle experimentally measured by INRIA on their testing road. The length of the route is 555m and the average speed of a cyber-car was 8.7 km/h. The road gradients that were used in the calculations are those of the INRIA testing road.
The main parameters of the cyber-car that were used in calculations are shown in Table 1.

Table 1. Main vehicle parameters used in the simulations.

Parameter	**Value**
Gross vehicle weight (GVW), kg	1250
Frontal area, m^2	2.31
Battery type	Lead – Acid
Maximal DOD	0.8
Basic battery weight, kg	130

Preliminary results of the simulations are presented here. The effects of the motor power and the vehicle average speed on the driving range and energy consumption were studied. The results are shown in Figures 2 – 5.

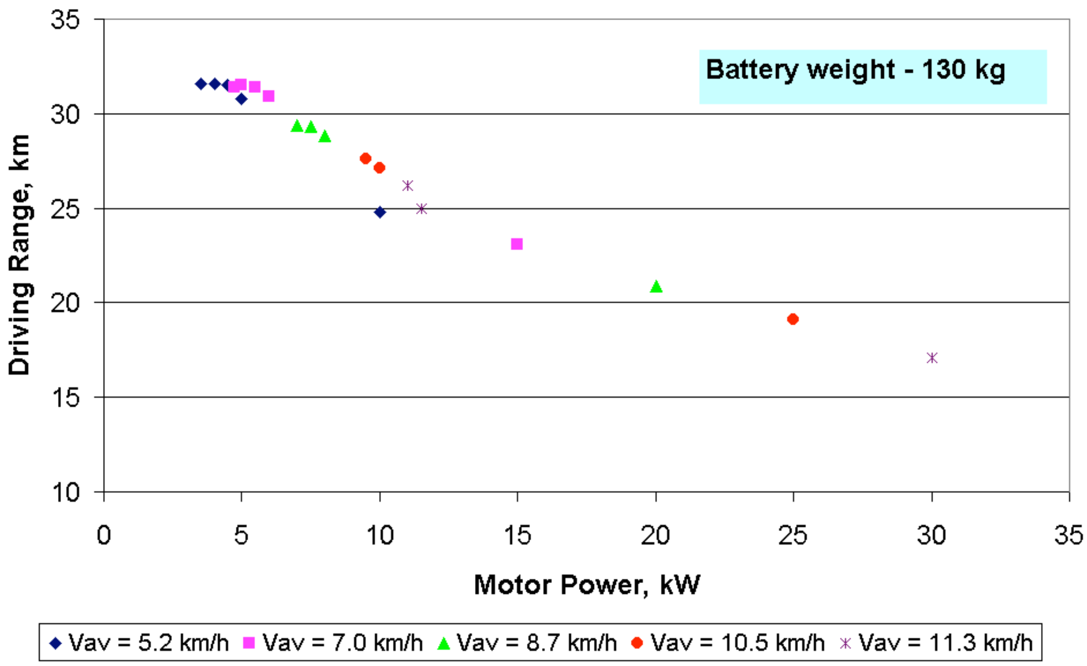


Figure 2. Effects of the motor power on the driving range of a cyber-car.

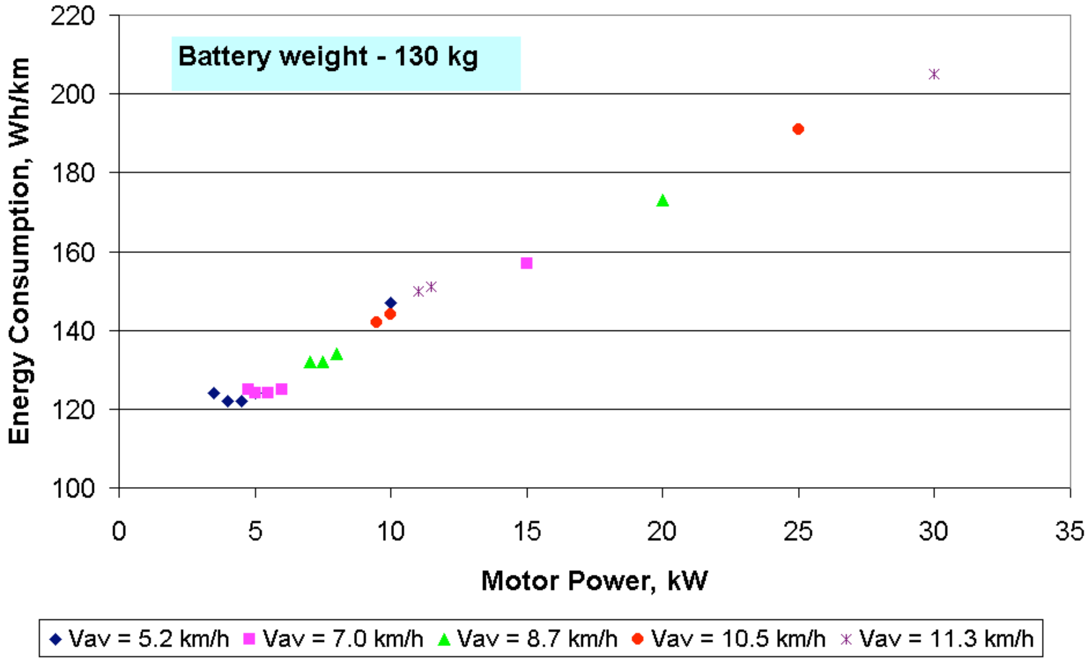


Figure 3. Effects of the motor power on the energy consumption of a cyber-car.

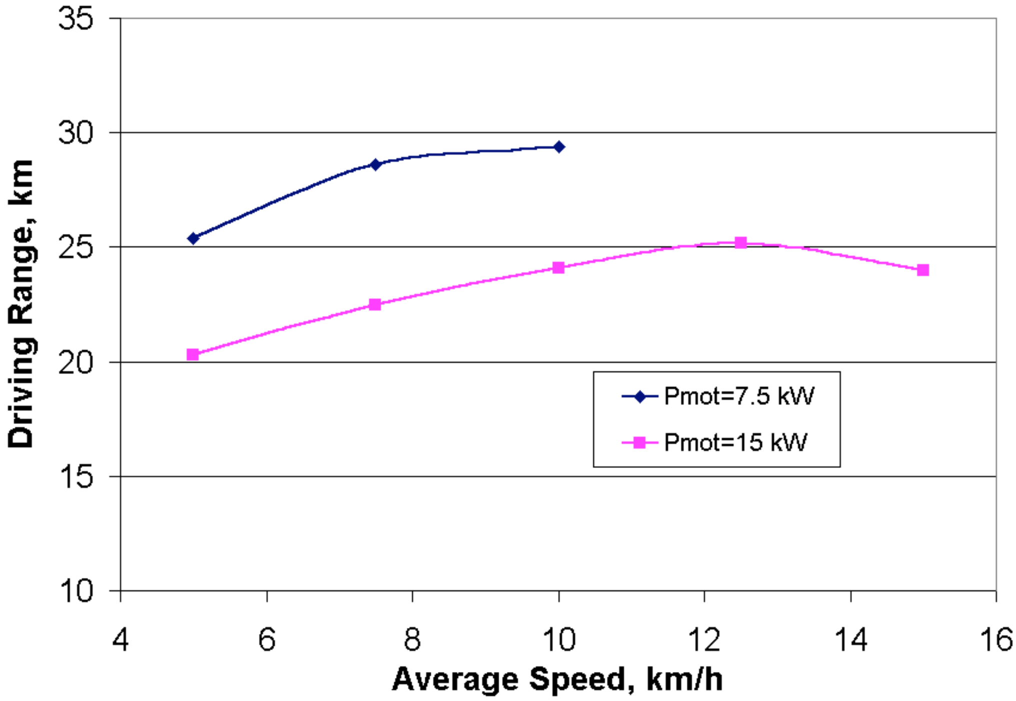


Figure 4. Effects of the average vehicle speed on the driving range of a cyber-car (battery weight = 130 kg).

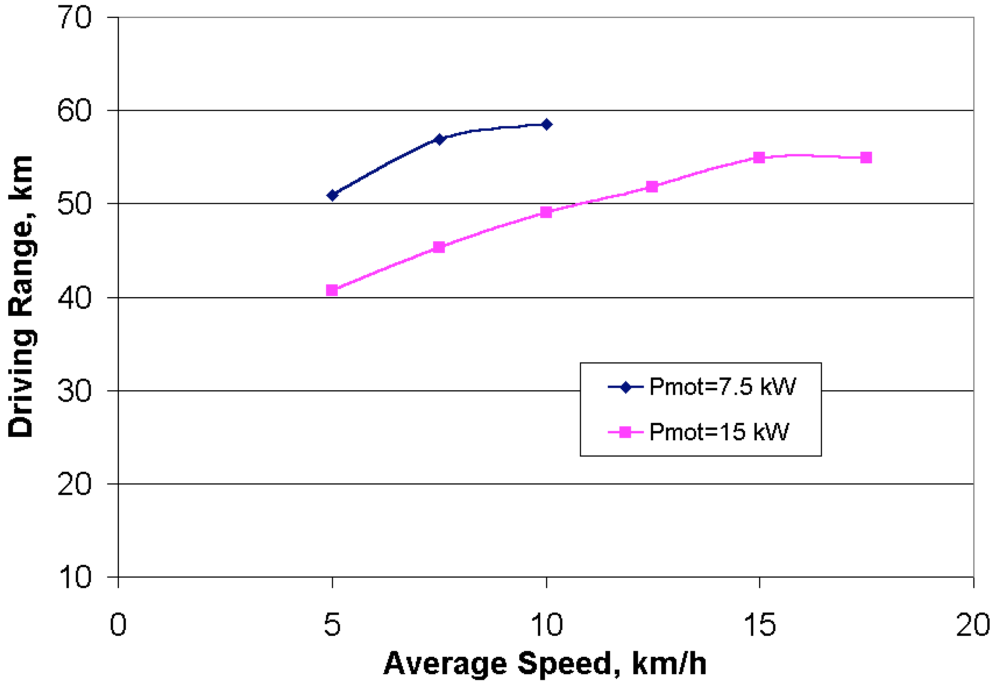


Figure 5. Effects of the average vehicle speed on the driving range of a cyber-car (battery weight = 260 kg).

As can be seen from these first results, there is an obvious influence of the vehicle's motor power on the energy consumption and, as a result, on the driving range. This follows from the dependence of the motor efficiency on the load factor. This means that the design of a cyber-car could be optimized for the specific planned driving conditions.
As may be observed from Figures 4, 5, the average vehicle speed (for the given driving route) could be optimized too, in order to achieve minimal energy consumption.
The model was also used for the assessment of the battery weight impact on the cyber-car's productivity. The vehicle productivity was defined as the product of the passengers' capacity and the driving range between rechargings. Calculations were performed for various average speeds and their results are presented in Figure 6.

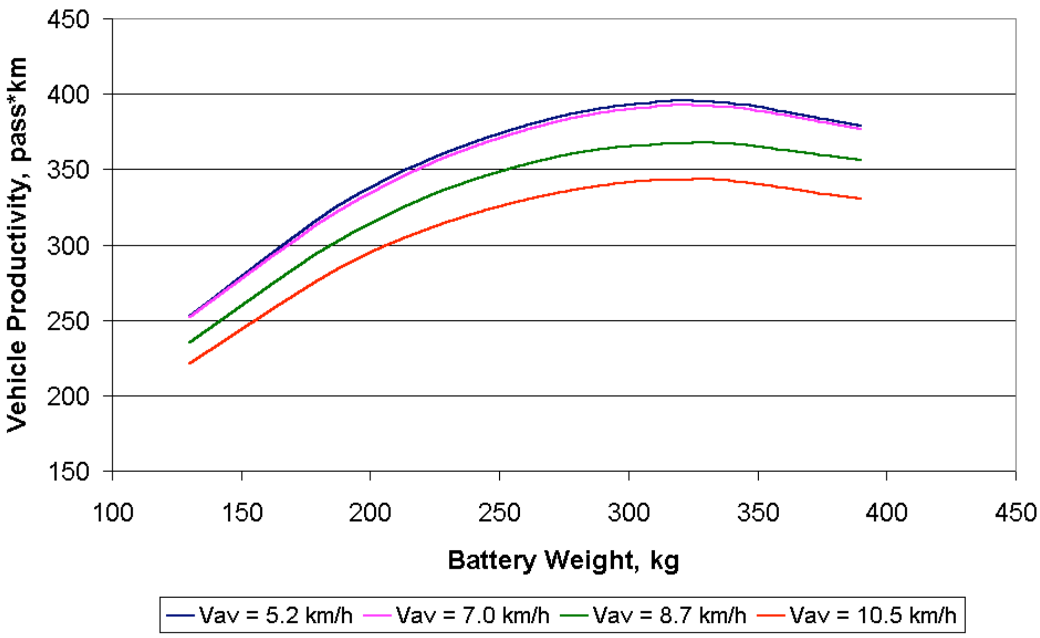


Figure 6. Impact of the battery weight on the vehicle productivity.

As anticipated, there is a clear optimum of the vehicle's productivity, which is more or less constant for different speeds. It may be concluded from this observation that the battery weight can be, and thus would be optimized.
Based on these first simulation results, it is expected that the model developed here could be useful in adoption and optimization of a cyber-car design for given driving routes, as well as in the driving routes selection process.

4. Conclusions

New technologies for infrastructure will optimize the use of the environment. It is the combination of using a vehicle and the use by the customer (passenger) of the vehicle. The passengers have to be supported with tools, which make it easy for him to have access of an automatic guided vehicle for transport of people (cybercar).

Effort is made to provide the passenger with an **easy to use and clear interface**. In the vehicle a user panel was developed which looks like a **horizontal elevator**. Passengers will go from A to B via C, etc. The corresponding buttons are located in that way.

Car-manufacturers are using more and more **LCD displays** with interaction to the user. With study and simulation an optimal solution for the lay-out has be looked for. Use of a **central rotary knob** with additional switches (also available on the touch-screen of the LCD display) will help the user. Important for the Cybercar is the use by **different characteristics of people**. Basic functions have been defined. The destination menu is one of the most important. To define the destination several ways depending of the kind of user can be followed with at the end the right destination. Graphical representation is done in several ways, but it has to be coherent with the use of the knobs.

For accessing a cybercar special attention is given to door-systems. Specialy, **elderly people** should access the vehicle in a easier way.

Using of **internet** and the availability of the **mobile phone** has led to new techniques. Passengers can request for a vehicle, see an overview route with the position of the vehicle. Passengers can be informed about the waiting time. In this way the **acceptance** of cybercars can be improved. With this kind of communication, payment for the cybercar can also be done.

Internet and mobile phone can be used for **remote** operation and servicing. An operator has not to be available continuously. He will be informed if something happens, can get an overview of the situation and can take appropriated measurements.

To have control over the vehicles a **fleet management** system is necessary. The basic of the system is to know the position of the vehicles and the position of the requester. The system makes a route planning to get a vehicle as soon as possible to the requested place. Information will be given about the arrival time. Also this information is given if the passenger has given the destination. **Real-time updating** can be given and is important for the acceptance of the system. Optimization is done for systems, which requires a continuous flow of vehicles during particular time of the day in combination with driving on demand during the rest of the day.

A **mathematical model** was developed to get optimal result for a given site with a given size, with certain stops and speed of the vehicle. Globaly, the ideal solution is to have stations at a distance of 0.5 km and the global operational speed (door to door) will be 18 km/hrs average. With the formula cities can calculate their solutions.

Batteries are at this moment mostly used. **Charging** batteries is an item that has been taken in account. Batteries have to be charged in time and in the right way to obtain maximum life cycle of the batteries and maximum availability of the vehicles. Algorithms are made available and can be used in the traffic management system to redirect a vehicle to a charging-station. A simulation model is developed and tested for several implementations. **Continuous charging** through the ground by high frequency magnetic fields has been developed and tested.

5. Annex 2: Bibliography (articles presented by partners during the project)

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