EUROPEAN COMMISSION
DG RESEARCH

SIXTH FRAMEWORK PROGRAMME
THEMATIC PRIORITY 1.6
SUSTAINABLE DEVELOPMENT, GLOBAL CHANGE & ECOSYSTEMS
INTEGRATED PROJECT – CONTRACT N. 031315

# WP 4 NEW MANAGEMENT APPROACH IN ADVANCED URBAN TRANSPORT SCENARIOS

| | |
|---|---|
| Deliverable no. | D4.1.2 |
| Dissemination level | PU |
| Work Package | WP 4.1 Operational Management |
| Author(s) | TRG |
| Co-author(s) | DLR, ETRA, CRF |
| Status (F: final, D: draft) | F |
| File Name | D4.1.2-PU-Traffic Management Strategies-CityMobil-FINAL Draft v2.1-TRG-05-05-2008 |
| Project Start Date and Duration | 01 May 2006 - 30 April 2011 |

# TABLE OF CONTENTS

1 **Executive summary** 4

2 **Introduction** 5

3 **CityMobil project scenarios** 5

4 **The SP4 Scenarios** 5

  4.1 Scenario S1: Town Centre with Advanced City Cars 6

  4.2 Scenario S2: Principal urban roads with an equipped "e-Lane" 6

  4.3 Scenario S3: Inner City Centre with Cybercars 6

  4.4 Scenario S4: Shared Traffic Space with automated buses 7

  4.5 Scenario S5: PRT 7

3 **The benefits of automation** 7

4 **Scenario 1: Town centre with Advanced City Cars (ACCs)** 9

  4.1 Introduction 9

  4.2 Real reference in CityMobil project 10

  4.3 Objectives 10

  4.4 Operations 10

5 **Scenario 2: Principal urban roads with an equipped 'e-Lane'** 11

  5.1 Introduction 11

  5.2 Real reference in CityMobil project 12

  5.3 Scenario 2a: Principal urban roads with an equipped 'open e-Lane' 12

    5.3.1 Introduction 12
    5.3.2 Objectives 13
    5.3.3 Operations 13

  5.4 Principal urban roads with an equipped 'dedicated e-Lane' 15

    5.4.1 Introduction 15
    5.4.2 Objectives 15
    5.4.3 Operations 16

6 **Scenario 3: Inner city centre with Cybercars** 19

  6.1 Introduction 19

  6.2 Reference model in CityMobil project 24

  6.3 Objectives 24

  6.4 Operations 24

7 **Scenario 4: Shared traffic space with automated buses** 29

  7.1 Introduction 29

  7.2 Reference model in CityMobil project 29

  7.3 Objectives 30

  7.4 Operations 30

8 **Scenario 5: PRT operations** 32

  8.1 Introduction 32

  8.2 Reference model in CityMobil project 32

8.3 Objectives 32
8.4 Operation 33
**9 Conclusion 34**
**10 Reference 34**

# 1 Executive summary

The final objective of CityMobil project is to analyse and develop new concepts and means of transport that permit a more effective organisation of urban transport in the future. This effect is measured in terms of low congestion, low pollution, safe driving, high transport quality, etc.

This document is delivered within work package 4.1. This work package has the task of identifying the new concepts and elements that will be needed by the new modern means of transport in order to offer the expected services, and setting the objectives that those new services must be able to fulfil. The results of this work are going to be latter used within subproject 4 to perform deeper and more specialised analyses.

Despite the fact that CityMobil project already considers 3 large demonstrators and several showcases where some of the contents of the project will be developed and analysed, these real demos still lack the characteristics necessary to develop some of the most innovative concepts within CityMobil. To cover this, some virtual demos (study scenarios) have been developed and designed in detail. These scenarios are:

- Town centre with Advanced City Cars
- Principal urban roads with an equipped e-Lane
- Inner city centre with Advanced City Cars
- Shared traffic space with Automated Buses
- PRT operations

By means of these theoretical scenarios, whose characteristics are described in this document, all the concepts under sub-project 4 will be studied, applied and analysed. The work presented in this document represents, therefore, an important basis for the rest of the work in sub-project 4.

# 2 Introduction

CityMobil sub-project 4, Operational Issues, will extend the current requirements, strategies and polices to the new Advanced Urban Transport systems (AUTS) that CityMobil is going to study. The aim of SP 4 is to identify the elements and the required organisational arrangements of AUTS in order to achieve the overall goals of the project which include sustainability, improved transport efficiency, less congestion, increased safety and improvements to the environment such as reduced noise and emissions. Hence, methods and tools from infrastructure planning to real time fleet management are all involved in the operational management of the new transport systems proposed by CityMobil.

In accordance with the vision presented by CityMobil (1), in fifty years we are likely to have an urban road network, which consists of two separate parts. One part will be substantially reserved for fully automated vehicles providing on-demand transport. The second part will be the “manual” network where partly automated vehicles will go under the control of a driver (with more or less assistance) and traditional (manual) vehicles will also be allowed.

# 3 CityMobil project scenarios

In several WPs of the CityMobil project, various scenarios for automated road transport have been suggested. These scenarios have been constructed from different points of view. For example, technology scenarios developed in SP3 are focused on vehicle, sensor and communication technologies in different operating scenarios, including:

- Scenario 1: Town Centre with partly automated dual mode vehicles/advanced city cars operating in historical city centre.
- Scenario 2: Principal urban roads with an equipped ‘e-Lane’ for reserved vehicles e.g. dual mode cars/buses.
- Scenario 3: Inner city centre with Cybercars operating in a restricted area in a taxi type service with pick-up at defined points, and set-down alone pre-defined ‘tracks’.
- Scenario 4: Shared traffic space with automated buses and dual mode vehicles

On the other hand, the travel scenarios developed in SP2 focus more on the journey patterns and land use impacts achieved by combinations of public/private and automated/manual modes. The fundamental changes will be the introduction of new types of vehicles, new infrastructures and new services. Of these, the introduction of driverless vehicles (or dual-mode vehicles in auto mode) is especially relevant to the traffic operation.

For purposes of investigating operational issues, the focus of CityMobil sub-project 4, slightly different scenarios need to be developed.

# 4 The SP4 Scenarios

Clear application scenarios are required in order to study the Operational Issues. These scenarios will need to agree as much as possible with both the technology and travel scenarios, but will have different emphases. It is assumed that operational issues such as traffic management will basically remain unchanged for vehicles with drivers, such as dual mode vehicles in manual-mode and advanced city cars (Note ACCs is used here to distinguish Advanced City Cars from ACC which is commonly used as the abbreviation for Automatic Cruise Control). The operational issues for driverless vehicles are new however, and will comprise the core part of the research to be undertaken. Scenarios developed in the WP are therefore closely related to the operations of driverless transport.

The scenarios developed in Sub-project 4, Operational Issues, are based on the four SP3 scenarios, but include a fifth scenario on PRT systems in order to consider all the advanced transport systems technologies studied in CityMobil project.

The 5 scenarios developed for investigation in SP4 are as follows:

## 4.1 Scenario S1: Town Centre with Advanced City Cars

This is based on SP3 scenario 1 but with the name and emphasis changed from “Town Centre with partly automated/dual mode vehicles/advanced city cars” to “Town with Advanced City Cars (ACCs)”. This reflects a need to focus on the operational and traffic management aspects of ACCs in urban environments generally. ACCs represent the ultimate stage in the development of private vehicles by motor manufacturers that is allowed under current legislation, and represent the step immediately preceding the introduction and use of automated systems in the form of dual mode vehicles.

The value of exploring this scenario is to show how traffic made up of ACCs can be operated and managed, and hence to show the best that can be achieved without going to full automation, and the changes in legislation that would be needed to allow the use of such (i.e. driverless) vehicles on public roads.

The CityMobil reference site for this scenario is the proposed demonstration in Genoa.

## 4.2 Scenario S2: Principal urban roads with an equipped “e-Lane”

This scenario is based on SP3 scenario 2, but is developed in 2 stages.

The final stage, and ultimate goal, is for a dedicated e-Lane that can be used only by vehicles that are specially equipped to use it, running in an automatic mode, i.e. dual mode vehicles. This will enable the formation and running of ‘road trains’ where vehicles are run in platoons at high speed to achieve maximum throughput.

However, while the benefits seem clear, considerable difficulties have been experienced in introducing such a scheme, which requires both a significant proportion of vehicles to be equipped and a dedicated infrastructure to be made available before the benefits can be realised.

An intermediate stage will therefore also be investigated in which an existing lane can be equipped or certified for use by dual mode vehicles, but which will also be available to normal ie driver controlled vehicles (including ACCs).

This system represents the next logical step from ACCs towards automated driving ie using dual-mode vehicles.

There are no reference sites for this scenario proposed currently in CityMobil.

## 4.3 Scenario S3: Inner City Centre with Cybercars

This is based on SP3 scenario 3. It represents the use of fully automated vehicles.

Current thinking is that this scenario should be confined inside a city centre, where usually the normal traffic is not allowed and there is only limited interaction with pedestrians or low velocity vehicles (such as bicycles), but it should not be limited to this situation.

The CityMobil reference site for this scenario is the Rome Demonstrator.

### 4.4 Scenario S4: Shared Traffic Space with automated buses

This is based on SP3 scenario 4 but is confined to the use of bus lanes that can be used by dual mode buses. Dual mode cars are excluded from this scenario (but are effectively dealt with in scenario S2 above).

The CityMobil reference site for this scenario is the Castellón Demonstrator.

### 4.5 Scenario S5: PRT

Personal Rapid Transit (PRT) is missing from the SP3 scenarios, but, it is thought, should to be included in SP4. It represents an automated transport system that has evolved from the point of view of a PT operator rather than a motor manufacturer. A system uses small vehicles running on a segregated guideway and with off-line stations. The vehicles can therefore run directly from origin to destination with no intermediate stops.

The CityMobil reference model for this scenario will be the Heathrow Airport Demonstrator, but modified to allow investigation of interaction with conventional traffic at level crossings, as in the system at Rivium.

The next section considers the benefits of automation. Each of the scenarios is then presented in more detail together with consideration of their potential for use in transporting freight. The final chapter considers the traffic management opportunities and strategies that will be investigated in the WP, and the method and approach to be used in investigating them.

## 3 The benefits of automation

Driving automation can be viewed as replacements of the functions that drivers perform every day in manoeuvres such as steering, braking and route finding. The ultimate form of automation will be the driverless vehicle where intelligence in the vehicle will take over all the tasks and responsibilities of a traditional driver on ordinary roads. Such a high-level of automation may not be feasible in the short to medium term. It is more likely that automated driving will first be realised in dedicated and protected environments such as on dedicated tracks or guideways, and on special lanes.

According to the vision of CityMobil (1), PRT vehicles, Cybercars, dual-mode vehicles and high-tech buses can all be operated in automated mode. Scenario 5 PRT represents a fully automatic system where PRT vehicles run on a segregated guideway. It is segregated from other traffic and pedestrians by using a dedicated infrastructure. Technologies for driving automation in such a dedicated environment are already at a practical level and a demonstration PRT system will shortly be in operation at Heathrow airport. On the other hand, Cybercars may not be segregated. They are fully automated vehicles that can run on conventional streets with other traffic, which may be limited to pedestrians and perhaps bicycles, but for safety reasons, they must then run at a lower speed. This is discussed in scenario S3 'inner city centre with cybercars'. The third form of driving automation, dual-mode vehicles and high-tech buses, can be operated in both automated and manual modes. They are discussed in Scenarios S2 and S4 respectively. It is expected that both dual-mode vehicles and high-tech buses can only be operated in automatic mode with appropriate infrastructure support ie on specially designated lanes. On ordinary roads, they are operated in manual mode.

The principal urban roads are designed to carry a large quantity of traffic at high speed. Driving automation with proper infrastructure support is desirable which will certainly help to improve safety and efficiency. Based on this vision, an 'e-Lane' concept is proposed in

Scenario S2 to support driving automation on principal urban roads. The ‘e-Lane’ refers to a physical lane, which is especially equipped and/or certified with a guidance automation system to allow advanced vehicles (e.g. dual-mode vehicles) to be operated automatically using the guidance system. More generally, an ‘e-Lane’ can be regarded as a special lane providing infrastructure support for driving automation.

A summary of traffic operation benefits achievable through driving automation is shown in Table 1. The benefits mainly fall into four categories: safety, environment (including energy use), convenience (comfort) and capacity. Depending on the degree of automation, the benefits that can be achieved vary considerably. For example, significant increases in capacity can be achieved by fully automated driving operation whilst limited increases can be expected for mixed traffic where both automated and manual vehicles are allowed.

**Table 1: Traffic operation benefits through driving automation**

| Category | ADAS | Automated driving open e-lanes | Automated driving dedicated e-lanes |
|---|---|---|---|
| Safety | Reducing incidents related with human limitations (e.g. observations, reaction time etc) and unsafe driving behaviours (speeding, inappropriate speed at bend and in bad weather etc.) | Further reducing incidents related with human limitations (e.g. observations, reaction time etc) and unsafe driving behaviours (speeding, inappropriate speed at bend and in bad weather etc.) | Eliminate all traffic accidents caused by human errors (about 90%) |
| Environment | Not significant (all future vehicles are assumed to use clean and quiet engine technologies) | By limited platooning e.g. of some commercial and/or transit vehicles, fuel consumption and pollution may be reduced. | More platooning and related benefits, plus fuel consumption and polluting emissions might be reduced by smoother traffic flow and improved aerodynamics of platoon.<br>Plus, automated vehicles can run in narrow lanes and so require less ‘land take’ |
| Convenience/ Comfort | Improve driving comfort and may support older drivers extend their driving life. | Provide equipped vehicles with carefree mobility for part of the journey. | Provide entire population with carefree mobility. Everyone onboard can do whatever he or she likes during automated driving. |
| Capacity | No significant improvement | By platooning some commercial and/or transit vehicles, 8~10% increase may be possible | The capacity of a dedicated lane might be doubled or even tripled. Traffic-management can affect individual vehicles. |

The 5 scenarios are described in detail below. For each scenario, the description, context and objectives are set out, and the key operational and traffic management issues are considered.

# 4 Scenario 1: Town centre with Advanced City Cars (ACCs)

## 4.1 Introduction

Scenario 1 can be described as a situation in which roads, demand, traffic rules etc, are more or less as today, but there is a portion of vehicles that have some specific scenario sensitive characteristics:

- ACCs vehicles are small compared with present cars (SMART Dimension) and are mainly used within the town including ring-roads and freeways;
- ACCs vehicles have equipment which allows them to be “always connected” with a Traffic Control Centre or local road-side unit and with a wide range of connectivity options (DSRC, WIFI, GPRS, etc)
- ACCs vehicles have equipment that allows them to be “mobile sensors” (FCD)
- ACCs vehicles have ADAS functions like intelligent speed adaptation, parking assistance, collision avoidance, stop&go, guidance etc.

Normal drivers, who behave, from the point of view of travel, in the same way as the drivers of conventional cars, use these vehicles. The point is what kind of ”context” we want to consider?

The idea is to set a scenario in a context where for example, there are conventional ITS systems well deployed within the town.

In this scenario:

- Traffic monitoring is a function able to cover the whole city for all type of roads including freeways: (TD (traffic detection), AID (automatic incident detection), UTC (urban traffic control) and FCD (floating car data) systems are widely available);
- It is possible to forecast traffic situations;
- Traffic management strategies are managed by some kind of “supervisor” able to define an “optimal” dynamic configuration of traffic flows over the whole network; this in turn allows the definition and provision of suitable information to system that can influence the behaviour of users (UTC, VMS (variable message signs), RG (route guidance)) in order to have a traffic distribution as close as possible to “optimal” as defined by the supervisor.
- Speed and Lane control through LCS (lane control systems) are available for freeways.

The above means that the starting point of the scenario for traffic management is a city where there is an ITS integrated system like that designed in the QUARTET project and successfully implemented in the city of Turin with also freeways well equipped with lane and speed control systems.

In this scenario traffic management strategies are not so different from those that could be implemented without the new ACCs. Reduce congestion, preserve environment, increase safety are all objectives of the traffic management strategies. The main issues / questions to answer that can rise from the introduction of ACCs are:

- What kind of impact can we have with different penetration levels of ACCs?;

- Are ACCs able to modify the relationship between traffic flow and travel cost? (Which in turn means to affect the "cost function" and the fundamental diagram)?
- Will the introduction of ACCs increase the chances that driver's behaviour will comply with the requested "strategy"?

The main aim of WP4.4 / scenario 1 analysis is to find answers to these questions using simulation methods and tools (macro and micro). Particular attention will be devoted to those ADAS functions that could significantly affect traffic flows (like ISA - Intelligent Speed Adaptation) or traffic distribution (like cooperative dynamic route guidance – multi-path guidance) where the guidance should also take into account in explicit way the safety issue. (With respect to this subject experience of the partner responsible in the IN-SAFETY project will provide an excellent staring point).

## 4.2 Real reference in CityMobil project

The reference site will be the city of Genoa, if it can be verified that the required data are available to build and run a simulation model. Alternatively the reference site will be Turin, where data are certainly available.

## 4.3 Objectives

Small cars equipped with ADAS, always connected with a control centre which can suggest the most convenient path (where convenience can be defined for the driver or for the "administration") provided a system that could have a significant impact on traffic performance within a city, depending upon the percentage of equipped vehicles.

The ultimate objective is to provide driving aids that will assist the driver to drive more efficiently and safely.

Work for this scenario will be the evaluation through simulation (macro and micro depending on the needs) of the effect on overall traffic performance of the main features of this vehicle.

- ACCs dimension: A first issue that will be investigated is the proportion of equipped vehicles. Using macro analysis of traffic flow and microsimulation it will be checked what would be the effect of having different percentages of equipped and unequipped vehicles operating in the city network..
- ACCs ADAS systems: A second issue will be the investigation of the effect of some of the individual ADAS functions, in particular those that could affect traffic performance including, for example, the ISA system in comparison with the capability to negotiate priority at signalised intersection.
- The third issue, likely to consume a large part of the resources allocated to this area of work, will be the investigation of the benefits of Dynamic Route Guidance (DRG) i.e. of having a "fleet" of vehicles, which in principle will be able to follow the specific routes that a "cyber-coordinator" will be able to produce. The questions to be answered will include: what should be the strategy to set the target traffic distribution over the whole city, and how should the routes to implement the strategy be determined?

## 4.4 Operations

Some key issues related to the operations of the scenario are presented in Table 4.1 below.

Table 4.1 Operational issues.

| | |
|---|---|
| **Road networks** | Conventional urban roads i.e. roads belonging to classes 1-4 of the Functional NAVTEQ classification. |
| **Intersections** | Normal intersections equipped with a UTC system and a Traffic Control Centre able to transmit information that can be used by ACCs vehicles (for example via WIFI). |
| **Vehicles** | Advanced City Cars (ACCs):<br>New city vehicles integrating zero or ultra-low pollution propulsion technologies and driver assistance functions such as ISA (Intelligent Speed Adaptation), parking assistance, collision avoidance, stop&go, guidance, etc.. These vehicles should also incorporate access control coupled with advanced communications (WIFI, data link with CO) in order to allow provision of several services including car-sharing.<br>Size of vehicle: city car (2~4 seats), small<br>Operating speed: up to 100 kph |
| **Pedestrians** | Normal interaction |
| **Operations** | ACCs cars are “always connected” with the Traffic Control Centre. These cars:<br>• Provide FCD (Floating Cars Data);<br>• Receive real time guidance information to follow routes computed in real-time at the control centre level (which are part of the traffic management strategy).<br>These cars are also able to follow speed profiles that maximise fluidity and adapt their speed to travel without stopping at traffic signals. |
| **Freight** | ACCs technologies can be used equally in cars and in freight vehicles of all sizes. . |

# 5 Scenario 2: Principal urban roads with an equipped ‘e-Lane’

## 5.1 Introduction

Principal urban roads are strategic arterials that carry a large proportion of the traffic in urban areas. They are used by all types of transport i.e. cars, Public Transport (PT) and freight vehicles as well as motorbikes, and in some cases also by bicycles and pedestrians. With increasing congestion at peak hours and (in the future) a growing proportion of traffic expected to be capable of automatic driving (i.e. dual-mode vehicles), special ‘e-Lanes’ may be established on existing principal roads to facilitate driving automation and thus improve traffic operations.

However, a ‘Dedicated e-Lane’ for use only by specially equipped vehicles would require extensive infrastructure construction and reserved space, and it would not be fully utilised if the penetration rate of automated vehicles was low. A migratory path via an ‘Open e-Lane’ scenario is therefore proposed. This has been chosen in regard to two main obstacles towards a widespread application of vehicle automation:

1. Space limitations that prohibit reserving dedicated lanes to automated traffic only. This ‘American’ approach to automated highway traffic is described in numerous publications since the early 1990s (e.g. as AHS Automated Highway System). While such systems are technically easier to implement than mixed-traffic scenarios, their application as “Dedicated e-Lane” might be quite limited in many European urban areas.
2. Conversely the quality of sensors and the capability of computer controllers to process and correctly interpret sensor data in complex urban traffic scenarios is – probably for many years to come – still not good enough to allow automated driving in the same way as human drivers can operate vehicles in cities.

The bottom line is that automated driving either requires significantly reducing the complexity of the environment – such as automated highway systems of the 1990s did by providing lanes separated from normal traffic – or it requires reducing the speed of the automated vehicles as it is done in many CTS or industrial automated transport systems.

As a compromise between these two limitations, a scenario can be described that reduces the complexity of the environment by restricting it’s first applications to certain road types while still allowing mixed traffic between manually driven and automated vehicles. Additionally, we do not postulate that the human driver can leave the control loop completely, but might have to stay in the loop to some extent in order to monitor the system and to be able to take over control in critical situations. We therefore prefer the term “highly automated driving” over “autonomous driving” in this situation.

Nevertheless, and as technology advances, in the future it seems likely that the market penetration of vehicles fitted with automatic driving capability will increase, So that as more and more vehicles become equipped to operate in dual mode, the open ‘e-Lane’ may eventually be made into a dedicated ‘e-Lane’ operation which is reserved for the exclusive use of dual-mode vehicles only.

Along this migratory route, two scenarios are proposed for principal urban roads with an equipped ‘open e-Lane’ and ‘dedicated e-Lane’ operation respectively. Fundamental properties of the vehicle, the road and the operational requirements for the two scenarios are discussed below.

## 5.2 Real reference in CityMobil project

There will be no real reference site for this scenario, as it is a completely new scenario and cannot be physically implemented. The scenario will be simulated in order to have a theoretical approach to this hypothetical situation.

## 5.3 Scenario 2a: Principal urban roads with an equipped ‘open e-Lane’

### 5.3.1 Introduction

In the ‘Open e-Lane’ scenario, dual mode vehicles can run in automatic mode, but other (i.e. driver controlled) vehicles are also allowed. This will limit the possible benefits of traffic operation that can be realised by driving automation.

### 5.3.2 Objectives

The objective of these scenarios is to provide an incremental path from ADAS to automation on a dedicated e-Lane via an open e-Lane scenario. Interim benefits should be obtained from the potential for forming platoons as more and more vehicles become suitably equipped, and some potential from the more productive use of time that would otherwise be spent driving.

### 5.3.3 Operations

In the open e-Lane scenario drivers must merge manually into the e-Lane traffic stream and then manually switch their vehicle into automatic mode. The vehicle will then accelerate or decelerate in an attempt to reach an operational ‘design’ speed (which can be determined by the vehicle itself, or from instructions received from the roadside) where it will remain unless it catches up with a vehicle in front. It will then automatically follow i.e. platoon with the leading vehicle (slowing down and accelerating with it) until it, or the leading vehicle leaves the e-Lane. The driver himself will need to determine when he wishes to leave the e-Lane. When he does, he must switch off auto mode and then change lane as normal under manual control.

Traffic operations for the open e-Lane scenario are summarised in Table 5.1.1 below.

Table 5.1.1 Operational issues

| | |
|---|---|
| **Road networks** | Urban arterial road, with an ‘equipped’ e-Lane that is also open to other traffic i.e. an Open e-Lane. The e-Lanes are especially equipped and/or certified for the use of dual-mode vehicles fitted with automatic lane keeping and platooning capability.<br>The e-Lanes may be physically delineated by means such as white lines, buried cables or magnets, and/or be identified as a series of co-ordinates that can be followed by an in-vehicle navigation system<br>Access to the e-Lane is open to all vehicles at any point along its length. No special access facilities or sections are required for vehicles entering and exiting the Open e-Lane |
| **Intersections** | No intersections exist along the length of an individual Open e-Lane. They are therefore most likely to occur on long lengths of road with no, or grade separated, intersections e.g. urban ring roads, freeways or motorways. |
| **Vehicles** | The Open e-Lane is open to all traffic.<br>Dual Mode Vehicles are able to support both fully automatic and manual driving. They can operate in automatic mode on an open e-Lane. The minimum requirements are for automated lane keeping and automated cruise/headway control.<br>Size of vehicle: ordinary car (3~5 seats), small i.e. light vans, buses and large freight vehicles |

| | |
|---|---|
| | Operating speed: up to around 130 kph<br>Due to the (likely) speed restriction operating on an open e-Lane, non-equipped vehicles might tend to prefer other (potentially faster or slower) lanes. |
| **Pedestrians** | The e-Lane should be segregated i.e. not accessible by pedestrians or cyclists because of ‘high speed’ operation. |
| **Operations** | **Within the open e-Lane: highly automatic for dual-mode vehicles; manual driving for other vehicles**<br>The level of driver involvement that is required during automatic operation is subject to research. Reading, working and sleeping are options that could be investigated. The level of involvement and the necessary sensors and intelligence to detect driver engagement, in order to bring him/her into and out of the loop, will need to be researched. Some of these issues will be addressed in CityMobil.<br>The necessary mix of centralized and de-centralized control, e.g. by the vehicles controllers and/or a multilevel computer system with I2V and V2I communications, is subject to research.<br>**Merge/de-merge operations:**<br>Entering and leaving an e-Lane is done manually, and should be possible at any time, if traffic conditions permit. Once on the e-Lane, the vehicle automated system must check the health status of the e-Lane. If automated operation is possible, the automated system must signal this to the driver, who can then activate the automatic driving mode. If an interruption occurs or the end of the e-Lane approaches, the vehicle/e-Lane system must signal to the driver to take over manual control. If the driver wants to leave the e-Lane at any other time, he/she can deactivate the automatic mode and leave the e-Lane under manual control.<br>An appropriate user interface is subject to research, namely, how to notify the driver that he/she can enter/exit automated driving mode and how the driver can confirm this. (Note: SP 3 will address this question). Another research question is whether any manoeuvre (e.g. increasing headway) should be performed before entering/exiting automated driving mode.<br>**Platoon operation:**<br>Platooning operation on the open e-Lane is possible between automated vehicles. Two possible situations will be:<br>1. Fixed tow-bar operation: a number of automated vehicles with the same origin and destination join into a platoon |

| | |
|---|---|
| | 2. Dynamic platooning: a number of automated vehicles following each other dynamically form a platoon. This will involve inter-vehicle communication. The opportunities for such natural platoon formation will grow as the penetration rate of automated vehicles increases.<br>**Outside the Open e-Lane: manual**<br>Vehicles are manually controlled.<br>**Transition**:<br>Drivers can undergo manual-to-auto transition at any time once accepted by the e-Lane, and auto-to-manual transition at any time.<br>Vehicles will need to signal an auto-to-manual transition request to the driver. If the driver does not take over manual control, the vehicle will need to enter an emergency stop procedure.<br>**Emergency:**<br>The driver of a dual-mode vehicle may take over control of the vehicle at any time, e.g. in an emergency situation. An extreme emergency manoeuvre might be an emergency stop.<br>Vehicles operating in auto-mode may declare an emergency and take automatic emergency stop action if the driver does not confirm an auto-to-manual transition request. |
| **Freight** | Freight applications are possible by using dual-mode freight vehicles. Dual-mode freight vehicles with a common origin and destination can be operated in a platoon (similar to tow-bar operation). |

As the interactions between the open e-Lane and all-purpose lanes are established using the manual operation of lane changing, they are not different from traditional traffic operations.

## 5.4 Principal urban roads with an equipped ‘dedicated e-Lane’

### 5.4.1 Introduction

The final stage, and ultimate goal, is for a dedicated e-Lane that can be used only by vehicles that are specially equipped to use it, running in an automatic mode, i.e. dual mode vehicles. This will enable the formation and running of ‘road trains’ where vehicles are run in platoons at high speed to achieve maximum throughput.

### 5.4.2 Objectives

To provide safe and efficient fully automated operation on principal urban road for dual-mode vehicles in dedicated lanes. Benefits should be obtained from significant increases in capacity through platoon operation, significant reduction in accidents as a result of driving automation, and the better use of travel time otherwise spent on driving.

### 5.4.3 Operations

In the dedicated e-Lane scenario, vehicles must be driven to a marshalling area where control of them is taken over by the infrastructure so that they can be formed up and merge into 'road trains' running on the dedicated e-Lane. Requirements for the operation of the scenario include:

- the need for special merge/de-merge facilities at exit/entry points
- the need to check the vehicle and the driver's 'health' before entering or leaving an e-lane.
- the need to operate the road trains efficiently and allow vehicles to enter and leave at intermediate points.
- special facilities for incident management and emergency services.

Traffic operations for the dedicated e-Lane scenario are summarised in Table 5.2.1 below.

Table 5.2.1 Traffic operations issues

| | |
|---|---|
| **Road networks** | Urban arterial road, with dedicated e-Lane<br>Special access and exit sections to enter and leave e-Lane |
| **Intersections** | No intersections but with entry and exit points. |
| **Vehicles** | Dual mode vehicles only (other traffic is restricted to use ordinary lanes).<br>Dual Mode Vehicles are able to support both fully automatic and manual driving.<br>Size of vehicle: ordinary car (3~5 seats), small i.e. light vans and buses, buses and coaches, and large freight vehicles<br>Operating speed: around 100 kph |
| **Pedestrians** | Segregated lane not accessible by pedestrians (or cycles or other vehicles) |
| **Operations** | **Within e-Lane: fully automatic**<br>No driver action is required during automatic operation so reading, working and sleeping are options, in principle at least.<br>All e-Lane operations will be controlled by a multilevel computer system with redundant safety controls. The central and vehicle computers will independently monitor spacing and closing speeds, initiating corrective action as necessary.<br>Platoon operation will be adopted to maximize the capacity of the e- |

Lane.

**Merge/de-merge operations: automatic**

Vehicles are automatically platooned in groups of fixed maximum numbers for running in the e-Lane, with gaps between platoons to allow for merging. Merge/de-merge will be controlled by multilevel computer system with redundant safety. A merge vehicle passing an access point will be ‘taken over’ by a control system which will implement a ‘health check’ to ensure the vehicle is fit for purpose (e.g. has enough fuel to complete the trip) and coordinate e-Lane traffic to create a gap. The on-board computer will control the vehicle to merge smoothly into the gap without driver intervention. This ensures safe and highly efficient operation.

A de-merge vehicle will be regressed from the e-Lane traffic automatically, slowing down and regaining a proper manual control headway on an off-ramp before driver take-over, and implementing a ‘health check’ again e.g. to ensure the driver is awake and will take over control.

**Outside e-Lane: manual**

Vehicles are manually controlled.

**Transition**:

Vehicles undergo manual-to-auto transition at access points to an e-Lane and auto-to-manual transition at exit points.

Each entry access point will have bays where each vehicle undergoes a health check. Vehicles then enter an acceleration lane along which the vehicles are taken over by the system for automatically merging with the e-Lane traffic stream.

Exit points have deceleration lanes onto which vehicles de-merge before slowing down and headway adjustment. On the deceleration lane, vehicles decelerate and regain headway suitable for conventional road traffic. Drivers are prompted to be ready for manual takeover and joining conventional traffic. If drivers do not respond to takeover the de-merging vehicle, the system will guide the vehicle into a safety bay and stop the vehicle.

**Emergency:**

Occupants of dual-mode vehicles may initiate emergency action at any time to divert off the e-Lane (at the next exit) or make an emergency stop.

The system will have an emergency mode in which all vehicles, which may be affected by a problem, perform a coordinated stop (including merging vehicles) while maintaining safe separations.

| | |
|---|---|
| **Freight** | Freight application is likely.<br>Freight vehicles could be despatched from one depot to another via access points along the 'e-Lane' route without the intervention of a driver. This could be particularly attractive for automated freight transportation between logistic centres.<br>Another possibility will be the use of dual-mode vehicles in a freight application where dual-mode freight vehicles are used in a similar way to dual-mode buses. Drivers would be required. |

Compared with traditional principle urban road operation, dual-mode vehicles will have the option to use either the e-Lane or a traditional lane. As the capacity of a single e-Lane could be much higher than that of a traditional lane, the overall capacity of urban corridors can be increased significantly and congestion can be effectively relieved. At the traffic operations level, the principal urban roads would consist of two types of lanes, e-Lanes and all-purpose lanes. The interactions between traffic on the different types of lanes are limited to interfaces at the entrances and exits of e-Lanes. This interface concept is new and represents a transition between manual and automated operations:

- The physical design of the e-Lane entrances and exists must support the operational strategy for the principal urban roads. For example, physical space may be needed to store vehicles queuing to enter an e-Lane, and exits must provide sufficient capacity to absorb traffic that is exiting an e-Lane and entering the all-purpose lanes.
- The operational management must ensure the safety and efficiency of interface operations.

Two important operational processes in interfacing between an e-Lane and all-purpose lanes can be describes as follows:

1. Enter automated driving mode

Automated driving can be defined as a type of driving where all driving tasks, e.g. longitudinal control, lane keeping, routing, obstacle avoidance, compliance with traffic law and traffic management, merging (if any), lane changing, overtaking (if any) will be carried out automatically without any human intervention. The vehicle will be under the control of either a central system or an on-board computer. Drivers are either not present (even though there may be someone e.g. a passenger, on board the vehicle), or if they are, they have no control of the vehicle in terms of driving and routing. In case of breakdown or emergency, the occupants should be able to initiate an emergency procedure to put the vehicle in a safe position. Step-by-step processes in entering auto driving mode are as follows:

- Drivers manually drive vehicles to an access point (a navigation system can aid the driver in routing, e.g. upon setting a destination, the vehicle navigation system can calculate where best to enter an e-Lane and the navigation system then guides the driver to that access point).
- Upon arriving at an access point, the vehicle will pass a health checkpoint. Vehicles that fail the health check will be regressed. Vehicles that pass will proceed to the acceleration lane where control of the vehicle changes to auto-driving. An in-vehicle display will indicate that the vehicle is under automated control. The system will coordinate the movement of the vehicle with a target gap in the e-Lane and guide the vehicle to merge into the e-Lane.

2. Exit automated driving mode (and enter manual driving mode)

This can only be done in a certain area (deceleration lane) with enough safety margins. After slowing down to a safe speed and regaining manual operation headway, a vehicle will prompt the driver by visual or sound signals to take over the control of the vehicle. The vehicle will not exit automatic operation mode until the driver has activated a control (e.g. a button) to confirm this. The vehicle will go to stop in a safe area if the vehicle has not been taken over by a driver. A clear indication needs to be shown to indicate if the vehicle is driven under manual or auto control.

Process:

- Vehicles approaching an exit leave the e-Lane and enter a deceleration lane automatically.
- Vehicle controls resume to appropriate settings typical (driver can set) for a human driver, e.g. a 2 sec headway, 30 mph speed.
- Upon reaching a manual driving state, the vehicle signals for the driver to take-over.
- Driver confirms and takes-over driving and the vehicle is now in manual-driving mode.

# 6 Scenario 3: Inner city centre with Cybercars

## 6.1 Introduction

The concept of cybercars is to provide fully automated vehicles. In current discussions within CityMobil the following applications were recognized:

1. Taxi-equivalent;

2. Public transport feeder;

3. Mixed traffic scenario within conventional roads.

The common property of cybercars in all application scenarios is full automation of the vehicles. Furthermore, it seems that Cybercars are following routing instructions received from a management centre. In this chapter, first a general point of view is followed, where the different scenarios are compared, not to be general, but to cover probable situations and the related functionalities.

From the traveller’s point of view, the cybercar concept is very flexible. It is working on demand and therefore the waiting time is reduced. Because of the full automation of the vehicle, travelers experience a greater comfort without sudden braking and turning. This all will be reflected in the functionalities ascribed to cybercars and in the description below.

For each of the applications different functionalities have to be included, some of them probably already covered by other (similar) applications elsewhere (e.g. dual mode). In brief, each application will be described first and compared within a table. Inputs for this table came from SP2 and SP. Also, other application scenarios may be discussed in the SPs and may be included in future.

Reference demonstrators are the Rome parking lot application and the Rivium ParkShuttle application, where Guidance is performed by a computer system based on odometric measures and references to little magnets in the road.

Table 6.1: Comparison of different Cybercar applications found within CityMobil

| Application<br>Characteristics | Taxi function within zones (mostly) free of conventional traffic (e.g. pedestrian zones) | Public Transport Feeder Function from within specific areas (mostly traffic free) | Taxi/PT Feeder Function Mixed with Conventional Traffic |
|---|---|---|---|
| Area | Specified zones **without** conventional traffic | Specified zones **without** conventional traffic | Specified zones **with** conventional traffic |
| Passengers | Individuals or small groups | Collected Individuals or small groups | Either one of them |
| Size of vehicles | Suitable for small groups (4-6 ps) | Large groups (up to 20 ps) | Either one of them |
| Access points (AP) | a) Fixed (Stations)<br>b) free (any point where Cybercars can travel)<br>[1] | a) Fixed (starting point and destination)<br>b) Partly free (starting point, destination fixed) | Fixed; variable access points highly unlikely because of interference with other traffic |
| Requesting Transport and Entering | a) from AP stations; by cellular phones to next AP<br>b) by cellular phones to demanded starting point or actual position | a) from AP stations; by cellular phones to next AP; at PT stations<br>b) by cellular phones to demanded starting point or actual position<br>c) by automatic detection systems, e.g. at parking lots | From AP stations; cybercars could also be deployed periodically |
| Exiting | a) only at fixed AP<br>b) at any point within defined zone and accessible by Cybercar | a) only at fixed AP; the destination AP is always a public transport station or other public building with high visitor frequency.<br>b) s. a) | Only at AP |
| Type of transport | Direct to destination, without further stops | Towards destination; additional passengers can be | Both plausible; direct to destination e.g. for single groups going |

---

[1] There is also a smooth transition between a) and b) thinkable, with quite a large number of access points along the tracks.

| | | | |
|---|---|---|---|
| | | picked up on way to destination | to the same place |
| Type of guiding | Magnetic/optical/wired Tracks; track-free with navigation within road | As described left; due to car size tracks are quite probable | Bound to streets of conventional traffic; fixed tracks may help in driving |
| Type of Area Network | Street network of inner cities, i.e. pedestrian (ped) zones; combination of narrow and wide streets, small and large (market) places; possibly pedestrian zones are crossed by streets with conventional traffic, so restrictions may apply for cybercars to operate in separated areas, or to take crossing these roads into account. | As described left; additionally large parking lots. | Street network of inner cities, mainly restricted to roads with conventional traffic; a combination of Cybercars driving within pedestrian zones *and* the surrounding streets may be thinkable (it would be very favourable to enter city centre not with private owned cars, because riding towards and into city centres saves a lot of time!); inner or outer suburbs where conventional public transport is not an option because of the low density and therefore relative high costs of employing drivers |
| Type of used network streets | Small size allows routing along all streets except very small ones. | Restricted to wider streets because of the size of the vehicles, in order to minimize interference with environment (obstacles and pedestrians). | As described left. On roads with conventional traffic special lanes, special equipped lanes or mixed traffic are alternatives. |
| Operating Speed | Relatively slow speed; probably within ped zones, only twice or triple speed of pedestrians is reasonable (reaction time of peds, avoiding collisions with moving objects etc.) | As described left. | As described left; within network of conventional traffic and shared lanes (conventional vehicles, dual mode cars etc.) a higher speed should be possible in order to fit into the traffic; however, in inner |

| | | | |
|---|---|---|---|
| | | | cities often speed limits exists or may be set for reserved lanes |
| Routing | Independent; calculated by central control and takes then actual information into account | As described left. | As described left. |
| Interaction w/ environment | Vehicles are equipped with highly developed sensors with high reliability and redundancy; other vehicles (other cybercars, bicycles), pedestrians, obstacles must be detected as well as sills etc. For cities with roads with conventional traffic crossing the ped zone special care must be taken. | As described left; more emphasis must be given to “adequate” driving as there are more passengers on board. | As described left; driving software must be more sophisticated, since lane changes, behaviour of other vehicles etc. must be taken into account |
| Vehicle control | Automated; supervised in its normal functions by central control (adequate speed, leaving of tracks etc.); inside control by video. Driving may follow tracks, therefore is restricted. | As described left. | As described left. |
| Fleet management | Central control manages availability of Cybercars, demands, redistribution, and service times, provides routing in accordance to local facts. | As described left. | As described left. |

| | | | |
|---|---|---|---|
| Limitations | a) in case of fixed stations, APs must be within reasonable reaching distance<br>b) in case of | | |

| | | | |
|---|---|---|---|
| | Cybercars on tracks, the tracks must be known to passengers in order to “define” access points dynamically | | |
| Remarks | | The function as a PT feeder has to be thought over, if one take into account that people also arrive at PT stations and destinations are distributed within the zones. A reasonable route finding to disembark individuals at different places is then quite difficult. Alternatively only specific drop-off points can be used as destinations. | Automated driving of cybercars in mixed traffic is quite close to an e-Lane Concept with e.g. dual mode cars, with or without (partially) separated lanes. The application scenario of border crossing between ped zone and conventional traffic is very interesting; normal car users have to park their car either next to the ped zone (finding a parking place might be difficult and expensive) or further away (requires modal change to PT and walking in the ped zone until destination is reached). Cybercars would function in this case as automated taxis, which are allowed to travel also within ped zones. |

There is sufficient overlap between the three applications. Especially, the second application may be a hybrid from the others. Feeder application for public transport is very useful if main public transport stations are within a certain distance from the city centre, which would be the third application scenario (and in effect is included there). However, for a better distinction, the scenario is listed separately, and additionally, it is mainly the Rome demonstrator. Additionally, cybercars can use separated lanes together with automated buses and dual-mode cars. Because this is between the scenario of mixed traffic and the scenario “area without conventional traffic” (in other words: interference only with other vehicles operating in automated mode and no pedestrians present), this is not considered separately.

## 6.2 Reference model in CityMobil project

The reference model in CityMobil will be the Rome demonstrator (mainly the second column). A small number of fully automated cybercars are running on dedicated tracks separated from conventional traffic. The tracks are provided with off-line stations and emergency exits and consist of two lanes. A control centre will supervise the system of depot, tracks, vehicles and scheduling / responding to demand. Passengers enter the cybercars at fixed stations. The control centre “knows” the number of vehicles entering the parking lot and where the vehicles will park, i.e. which nearest stop has to be served in what expected time in off-peak hours.

## 6.3 Objectives

The objective is to offer a central managed demand oriented system, which provides transport within mostly separated lanes for passengers or goods. Cybercars shall replace shuttle services and provide frequent services for passengers or goods. Fleet management and passenger and freight handling management shall grant optimized demand management.

## 6.4 Operations

Based on the table above the following table is filled in with aspects common for all types of cybercars (i.e. summary of the table above).

Table 6.2 Operational issues

| | |
|---|---|
| **Road networks** | Roads and places within city centres, suburbs; large scale: possibly mixed area, with pedestrian zones, large plazas, crossing roads with conventional traffic and some roads in the surrounding where Park & Ride places and main public transport stations distant form the city centre can be reached; small scale: area of only one type of road infrastructure, e.g. large places, road network; cybercars are used for designed transport tasks (e.g. towards hospitals). Suburban centres can be connected to public transport.<br>The network type strongly depends on area chosen: in old city centres with a network of (small to large) roads the network is identical with selected road network; in urban areas with large places networks may consist only of freely chosen routes.<br>Routes along roads are predefined by markers; these can be lines on the road, painted or wires, or pure navigational systems based on GPS; (both have their implications for safety etc.).<br>The range of the cybercar is a maximum of 2-3 kilometres |
| **Intersections** | Two different intersection types: i. Intersections with normal roads priority rules and safety aspects for other crossing types of vehicles; ii. Intersections with crossing cybercars can be controlled by fleet management; additionally other vehicle types must be detected as above |

| | |
|---|---|
| **Vehicles** | Cybercars are supposed to be fully automated vehicles; no driver is present; after entering a destination by passengers, cybercars are following calculated routes for the start-destination relation. Besides the calculation of the routing (which can be done either in the cybercar itself or more likely by central control), cybercars accelerate, steer and decelerate themselves with help of multiple sensor inputs and sophisticated software.<br>**Within** areas otherwise mostly free of conventional traffic: driverless cybercars, other slow moving vehicles, bicycles<br>Size of vehicle: ordinary car (3~5 seats), small i.e. light van sized buses and freight vehicles<br>Operating speed: approx. double to triple pedestrian speed (see below)<br>**Outside** these areas, mixed traffic: faster moving vehicles (~30 kmh), interaction with all types of vehicles but no pedestrians<br>Taxi function: 5-6 passengers, Public Transport Feeder: ~20 passengers<br>Vehicles must conform to safety requirements for passengers such as safe acceleration/deceleration, possible open vehicle sides as demonstrated in some current designs of cybercars (used as slow moving individual taxis). |
| **Interactions** | Pedestrians and cybercars may share the same space, together with other slow moving (within ped zone) and moving vehicles with various speeds (outside ped zone); they must respond to pedestrians, bicyclists etc. in the environment which do not always expect motorized vehicles in pedestrian zones<br>Automated driving is defensive, i.e. other participants should never be in danger at any time. |
| **Operations** | **Guidance**<br>Different types of cybercar guidance are possible: guidance by sensor input and guidance by navigation with positioning systems. Guidance by sensors means the registration of data specified for software evaluation. This can be a guiding system buried in the roads (wires, painted lines etc.) or optical objects identified for guidance. Whereas buried guiding systems leave almost no control to the vehicle in lateral movement (with implications that pedestrians are always safe outside the guidance track, but obstacles can't be bypassed) optical systems are more flexible. Most flexible in deviation from a pre-designed route are cars equipped with positioning systems allowing them to follow a virtual path. In cases of unexpected obstacles or route realignment only the virtual path has to be changed.<br>**Interactions**<br>Interactions between cybercars can be controlled by central control. |

Interactions with other vehicles and pedestrians must be controlled by cybercar intelligence (stimulated by multiple sensor input).

Interactions can also include platooning of several cybercars to increase the speed of response to demand and the exploitation of available space.

In cases where cybercars are bound to the area mainly without other traffic (pedestrian zones), a transition to conventional traffic space is not needed. However, some old cities may contain roads for conventional traffic crossing the pedestrian zone. This may be exceptional, but must be dealt with. Crossing mechanisms or full stop on either side of the conventional road may both be valid options.

Interactions with other vehicles must obey safety rules. Where more and more cybercars are deployed, some of them may be grouped into platoons where they follow a feeder function for public transport. In this case, some of the safety rules may be modified in order to improve efficiency. Operations modes are then similar to e-Lane-Concepts (see section 5 above). Platoons within pedestrian areas may block pedestrians for a little while, which may decrease the acceptance.

**Demand Management**
Demand response can be organized by cybercars themselves in an ad-hoc network or by central fleet control. Event calendars, schedules of mass transport systems, knowledge of time-varying demands, and advance booking systems may be the basis for demand management, which has to cope with actual local demands. For high acceptance the time to respond to demand should be reasonable low (~2 min).

**Depot management**
Depot management including service and maintenance periods must be accounted for within the central fleet management in order to provide the exact number of cybercars which is necessary to face the expected demand, including travel times towards access points.

**Maintenance and service cycles**
Vehicles must be recharged, cleaned, inspected, repaired and occasionally parts have to be replaced on a regular or frequent basis. A logging system is needed for holding information on the present vehicle state, planned charging and cleaning times as well as future inspection dates.

**Central control**
Cybercars in principle could act autonomously: they are provided with sensor intelligence and my move according to a routeing system on board, reacting on the inputs of passengers. However, this is highly unlikely. At least the task for optimal distribution of cybercars cannot efficiently be done without central control. Central control will control the position of each car (fleet management), watch over incidents with cars or between cars and others, organize maintaining services, supervise the interior of the cars, for example occupancy.

Within mixed traffic in moving together with conventional traffic,

| | |
|---|---|
| | Cybercars can be treated as dual-mode vehicles in their automated driving mode. Access control is implicit, and priority rules can be taken over from dual-mode cars. The central fleet control may exchange information with the traffic management system and can benefit from the advantages of automated driving, which can be taken into account for routeing the vehicles.<br>**Emergency:**<br>Occupants of a cybercar may initiate emergency action at any time to make an emergency stop and to inform the fleet management authorities. Since cybercars are moving on special routes, other cybercars using the same route may be affected by the emergency stop. Central fleet management may have the options to i. choose diversion routes for cybercars other than the incident vehicle; ii. move cybercars locally around the incident vehicle; iii. move the incident cybercar aside to a safe place (reasonable, because pedestrians and other vehicles might be hindered or even in potential danger).<br>**Security:**<br>The security of the passengers becomes especially important in driverless vehicles like Cybercars. Several measures can be taken in order to improve this aspect, such as access controls to identify and limit the amount of passengers; surveillance and emergency call systems… |
| **Freight** | Freight applications are likely, but with limitations.<br>Freight vehicles can use the same space and act the same way as passenger cybercars. However, in the classical setup as taxis, the freight load is quite limited. In this case, special express couriers may be an application. For larger vehicles the load may be increased, but unloading within a few minutes must be organised or loading/unloading bays must be installed.<br>The cybercars can work on demand; therefore on-demand logistics schemes can be implemented.<br>Single package or multiple package transport for each car is an option. Standardized containers may help for transport and also for quick loading and unloading also with automated systems. With a single destination and multiple origins system certain communal services can be organized, e.g. garbage collection. |

All functional areas described in SP4 (see Deliverable D4.1.1 Concepts, elements and processes involved in various automated system options') are involved in the cybercar scenarios, except providing Advanced Driver Assistance. Since no drivers are present special emphasis must be focused on the automated driving system and central fleet management.

Automated driving includes a whole range of sensors to move safely in the environment. From the functional architecture point of view, this has little impact on the architecture itself, except for incidents where the driving system is not working correct. On malfunctioning, this must lead to a chain of reactions including informing the central fleet management.

Central fleet management does not only take action in smaller or larger emergency cases. In general, it organises the distribution and availability of cybercars. In the case of small “Cybercabs” only the status and future destination and arrival time is important for logistics. For the transport feeder function, also the number of free seats and current position is important to direct the cybercar towards the next access point in order to pick up passengers. A permanent link or emergency link may be necessary for security reasons, and the position of each cybercar is retrievable at any time. Central fleet management may also do routing services.

For some tasks, additional information may be transmitted, e.g. the number of passengers entering the cybercar, in order to calculate future deployment on the basis of expected demand.

The central element therefore is a usually not-permanent link between each cybercar and a fleet management centre, which can be made permanent if needed. Depending on the link, frequency range and bandwidth must be supplied. Additionally, links between cybercars themselves may be an option, firstly for mutual interaction along tracks and at junctions, secondly for a self-organizing distribution of cybercars. In the last case, advanced algorithms for wireless information transmitting must be implemented. The advantage would be, that a failure of the fleet management centre would not lead to a break down of the whole cybercar transportation system

From an operational viewpoint, it is necessary that passenger acceptance is high. Therefore some points must be kept in mind, when cybercars are implemented, which vice versa have an influence on the operations. 1. Capacity must be sufficient. Acceptance can only be achieved if the required features (demand response within 2 minutes etc.) are available to passengers at all times. Single-track roads where two-way traffic is not possible because of restricted available space may hinder a successful implementation. 2. Speed must be adequate. Acceptance can only be achieved if passengers feel comfortable with the speed, as well as pedestrians in ped zones. 3. Passenger information at any time is an important point to be considered, which has impact on the cyber link between cybercars and central control.

From a traffic management point of view, crossing roads with conventional traffic is critical. Communication between cybercars and the intersection infrastructure, or between central control and the intersection infrastructure is necessary to organize the crossing. Care must be taken that conventional traffic must not wait an unlimited or unreasonable long time. Special signs for cybercars may be implemented, and cybercars should be able to recognize and interpret conventional signs and traffic signals. Also, special electronic signals and warnings transmitted by the tracks or by central fleet control can be a component of the guidance system. The following picture illustrates the crossing of cybercars with conventional traffic.

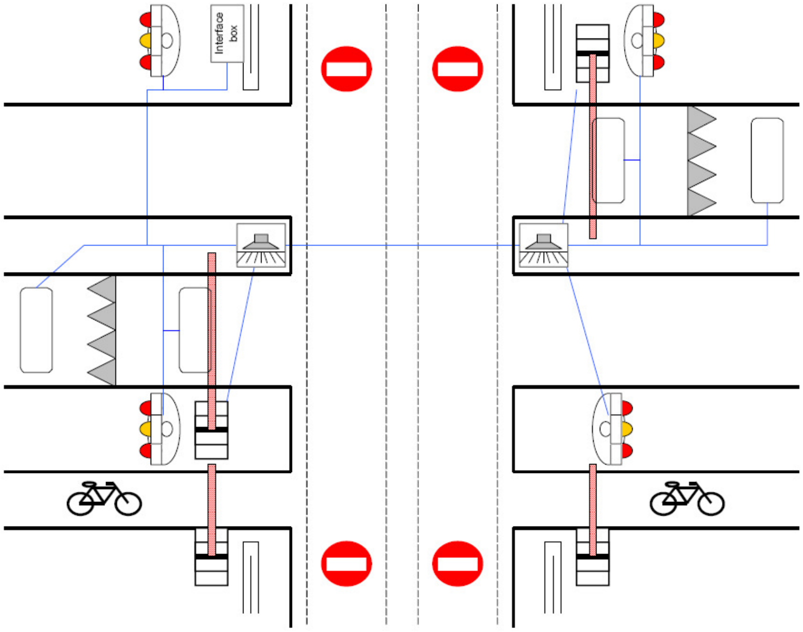

Figure: Example for cybercars crossing roads (from CyberMove D2.2 conceptual design report, Rivium Site) (*for further use permission for reproduction should be asked for)*

# 7 Scenario 4: Shared traffic space with automated buses

## 7.1 Introduction

This scenario proposes a high-tech bus system coexisting with the normal traffic in an urban environment.

A high-tech bus system is a public transport system, which connects various districts of a city and allows people to travel from their homes to work or to the city centre on a given time table without being influenced by traffic jams or road congestions and independent of their own vehicle.

This high-tech bus system offers a large number of advantages such as environmental friendliness, independence of personal vehicles, fixed schedules, smoother traffic flow, etc. The systems are operated on dedicated bus lanes. These are often delineated and separated from the normal roads by shoulders, typically covered by grass or trees. High-tech bus systems should have the capability of automatic guidance and automatic stopping at the bus stops, intersections, and pedestrian crossings.

## 7.2 Reference model in CityMobil project

The reference site for this scenario is the Castellón demonstrator. The Castellón demonstrator is one of the three big demonstrators in the CityMobil project and consists of a guided high-tech bus system. This system is structured around two corridors, with a length of more than 40 Km, in which a reserved platform for the vehicles of public transport will be built. On this platform a hybrid system of guided buses will be used. The Castellón demonstrator will provide considerable flexibility of operations as the buses can either run on the dedicated lane or on any other part of the road network as required.

## 7.3 Objectives

The primary goal of this scenario is to show how the advanced driving assistance (ADAS) technology can be applied to a public transport system. Another objective is to settle the necessary conditions and requirements to implement this kind of system and the benefits it can produce.

## 7.4 Operations

The following table summarises the different operational issues regarding this scenario.

Table 7.1 Operational issues

| | |
|---|---|
| **Road networks** | Dedicated bidirectional lanes where the buses need to bypass congestion, specially equipped buses can operate normally on the rest of their routes. These dedicated lanes will be suitable for buses, that is, wide enough for them to circulate, and will be equipped with magnets for lateral guidance in the automatic systems of the high-tech buses. |
| **Intersections** | When the dedicated lanes intersect with normal roads, high-tech buses will be given priority over private normal traffic.<br>In the cases where the high-tech buses share the roadway with normal private vehicles, they become normal buses therefore they will have to obey the normal traffic priorities. |
| **Vehicles** | Hybrid high-tech buses with electrical traction and an automated guidance system equipped with sensors for driving lane detection to provide lateral guidance. A driver will be on board in order to monitor the system and to ensure the safety of the overall system.<br>**Within** the dedicated lanes the high-tech buses' guidance system is fully automated and even approaches all bus stops in automated mode. In spite of that, a driver will be on board at all times in order to monitor the system and to ensure that the route is being followed safely and will always be able to recover the control of the bus when required.<br>Average speed will be in the range of 0-50 km/h, longer distances between two bus stops allow higher velocities of up to a maximum of 80KM/h<br>**Outside** these lanes, they will mix with normal traffic and will become normal driven buses. |
| **Pedestrians** | Pedestrians and high-tech buses may share the same space, especially at the bus stops. At these zones, the buses will be manually driven by a physical driver to ensure the pedestrian's safety.<br>Outside the dedicated lanes the high-tech buses will act as normal buses, interacting with other normal vehicles. In these cases the bus driving will be totally manual. |

| | |
|---|---|
| **Operations** | **Guidance**<br>The dedicated bus lanes are equipped with magnets, at the same time the high-tech buses are equipped with sensors for driving lane detection to provide lateral guidance. In the longitudinal direction the vehicle velocity is also provided by an automated control system.<br>A sensor system to detect and avoid obstacles in front of the vehicle is also needed, especially when the vehicle approaches an intersection, a pedestrian crossing or a bus stop.<br>Furthermore I2V and V2I communication systems have to be mounted in the vehicles to exchange information (e.g. vehicle position and vehicle velocity) between the buses and the traffic management system, especially at critical points such as pedestrian crossings, intersections and bus stops.<br>**Demand Management**<br>In this scenario the high-tech buses will follow a timetable, so the system will not provide an on-demand service. Demand management will consist basically of building event calendars, schedules of mass transport systems, knowledge on time-varying demand, which will be used to develop the schedules that will to cope with actual local demands.<br>**Central control**<br>High-tech buses in principle could act autonomously as they are provided with sensor intelligence. However a Central control will be needed in certain cases. The traffic management control will have to track the vehicles on the dedicated lanes, to control their position and velocity, and will monitor and control all the intersections, pedestrian crossings and bus stops, regulating the velocity of the buses and the traffic signals of the lane as the bus approaches the intersection, pedestrian crossing or bus stop.<br>**Emergency:**<br>The driver of a high-tech bus may initiate an emergency action at any time to make an emergency stop and to inform the Central Control and the traffic authorities. When a high-tech bus stops in the special lanes, other buses using the same route may be affected by the emergency stop. Central management may have the option to move the incident high-tech bus aside to a safe place (reasonable, because pedestrians and other vehicles might be hindered or even in potential danger) in order not to disturb other high-tech buses in the same dedicated lane. |
| **Freight** | Freight applications are likely, but with limitations.<br>Freight vehicles may use the same space and act in the same way as high-tech buses, or the buses may operate as 'post buses' |

| | |
|---|---|
| | carrying letter sand parcels. Loading and unloading within a few minutes must be organised or loading/unloading bays must be installed.<br>Single package or multiple package transport for each bus is an option. Standardized containers may help for transport and also for quick loading and unloading also with automated systems. With a single destination and multiple origins system certain communal services can be organized, e.g. garbage collection. |

# 8 Scenario 5: PRT operations

## 8.1 Introduction

In order to cover PRT, and to include all three demonstrators in our analysis, we need to develop a new scenario. The reference, obviously, will be the CityMobil Heathrow Demonstrator. Some concerns were considered: the network proposed for Heathrow is too simple to be amenable to an informative analysis; ATS may not be willing to let us use their model out of concern that the results of our analysis are not positive. Nevertheless, as the only system evolving directly from Public Transport considerations, it is important to include PRT in our research, and to look at the potential for interaction with conventional traffic at level crossings as demonstrated in the Rivium system in Rotterdam.

The Heathrow airport demonstration is a personal rapid transit system, which takes passengers non-stop between their origin and destination. The system provides immediate response to each passenger’s trip demand using small automated vehicles running on a dedicated track that links a passenger car park and the new Terminal 5.

The scenario for operational issues is based on this Heathrow Airport demonstration. The vehicles are controlled by a supervisory computer system, which provides an on-demand service. Stations are offline so that vehicles go directly to their destination, and do not need to stop at intermediate stations. For the investigation it is assumed that the track also has a level crossing with a four-lane road with medium traffic demand. Fundamental properties of the vehicle, the guideway and the operation of the system are summarised below.

## 8.2 Reference model in CityMobil project

The reference site will be the full network planned for Heathrow with one or two level crossings introduced (as with the Rivium system) to show the effects on system operations of interaction with conventional traffic.

## 8.3 Objectives

The objectives of a system are to provide a PRT system offering a demand responsive service with minimum waiting times.

## 8.4 Operation

PRT uses small vehicles running on a segregated guideway and with off-line stations so that vehicles can run directly from origin to destination with no intermediate stops.

Traffic operations for the PRT scenario are summarised in Table 8.1 below.

Table 8.1 Operational issues

| | |
|---|---|
| Road network | Small guideways (low loading) that can be located above ground, at ground level or underground.<br>Dedicated infrastructure with guideways and stations on a coupled PRT network. |
| Intersections | Level crossing with conventional vehicular traffic (assumed) |
| Vehicles | Fully automated vehicles<br>Size of vehicle: small vehicles for exclusive use by an individual or a small group (up to 6 passengers). Freight vehicles not feasible because of low-load design of guideways, but transportation of small freight packages could be possible.<br>Operating speed: up to about 30 mph (45 kph) |
| Pedestrians | Segregated guideway not accessible by pedestrians, cycles (or other vehicles) |
| Operations | Fully automatic<br>Direct origin to destination service on demand rather than on fixed schedules.<br>The operation of the system, including vehicle movement control, stop at station, dispatch, routing and service (e.g. battery charging) are managed centrally using control software.<br>**Vehicle Control**<br>The vehicles are controlled autonomously. Once the vehicle has received its instructions from central control it will continue to its destination autonomously.<br>**System Control**<br>The central control system responds to the passenger's request by allocating a vehicle for the journey and instructing the vehicle on the required path for that journey. The central control also manages level crossing operation. Conflicts between PRT vehicles and road traffic are resolved by traffic light signals and level crossing barriers. The management of empty vehicles is also subject to central control, which ensures that vehicles are sent to where they are needed.<br>**Emergency:**<br>Occupants may initiate action at any time to make an emergency stop. Central control may initiate system shutdown in case of system |

| | |
|---|---|
| | malfunction.<br>**Security:**<br>A CCTV video-camera surveillance system will be operated in a 24/7-manned Control Room in order to detect and promptly intervene in case of any vandalism or personal attacks. |
| Freight | Freight applications are not intended, but transportation of small packages would be possible. |

Both normal operation and incident scenarios are possible. In normal operation, an optimal number of PRT vehicles are in operation to provide a demand-responsive service with a typical waiting time of less than one minute. Level-crossing operations are optimised to minimise delays to both PRT and road traffic. In an incident scenario, a broken down vehicle blocks a section of track. A recovery team (on a PRT vehicle) is immediately despatched to clear the blockage. An incident management strategy is put into effect to minimise the impact of the incident, including maintaining operations on unaffected sections and traffic recovery operations.

# 9 Conclusion

This document shows how the different CityMobil scenarios have been defined, regarding Operational management issues. The main objective in SP4 from now on is to take the concepts, developed here, forward through the rest of Work Packages to develop Service Customisation and Traffic Management Strategies and finally to combine all the results in WP4.5 on Integration.

# 10 Reference

1. CityMobil deliverable D2.1.1 ‘State of the Art Review’, 2007