

The *mobilicity* PPT Automated Urban Mobility System “See the Future Today”

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The *mobilicity* Personalised Public Transport urban transport system has been developed to match the needs for mobility in the large cities of tomorrow. The whole basis of the PPT approach is that the coming decades will require a radically new methods of transport within these urban areas. It is vital that the three greatest problems of congestion, energy use and emissions (both local and global) are addressed in an innovative manner. The new *mobilicity* PPT system involves some fundamental changes in the use of electric drives, especially with fuel cells.

Keywords: Sustainable Mobility, Transportation Systems, Public Transport, Buses, Electric Drive.

1. INTRODUCTION

Capoco Design concentrates on public transport projects across all the global markets and has successful products on all the continents. These products centre on both city buses and long distance coaches. The recent work has been new low-floor city buses for Europe, Asia and North America. The Capoco bus projects have taken about 65% of UK city bus sales over the past fifteen years, with market leaders in all the sectors.

The *mobilicity* project had its first seeds in 2002 when the Capoco Design Limited company reached its 25th year of incorporation since it was formed in 1977. The approach at Capoco is always to look forward so the company decided not to concentrate on a reprise of its past activities, but to investigate the fairly urgent requirements for future city mobility.

With this public transport background, it seemed natural to commission a research project into the needs of city transport over the next 25 years up to 2027. This was to take into account all the major trends acting on the transport scene as a whole. This particularly included population growth and the rural-to-urban drift. It was therefore logical to study the transport needs of the mega-cities that will increase in number as we move from a 50% urban share of a 6 billion global population, to a 65% urban share of a 9 billion global population.

This demographic trend is being accompanied by an ageing population profile in many countries, with its impact on national finances, individual wealth, social exclusion and different mobility needs. These effects will run parallel to the equally well-known trends of reducing oil supplies, environmental pressure on local and global air quality and ever-greater societal losses through traffic congestion.

2. BACKGROUND

The formal *mobilicity* program started in 2003 as research carried out by the joint program undertaken by Capoco and the Royal College of Art, London. The project

addressed the future travel needs for urban areas by studying the journey profiles for travellers in London, Istanbul and Hong Kong. The method included travelling with typical individuals on journeys for both business and social reasons. Likewise, the commuters were across a range of wide age and social groups.

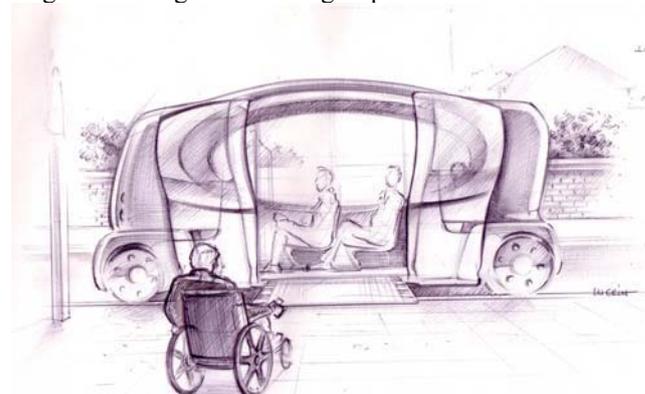


Fig. 1 The need for universal access

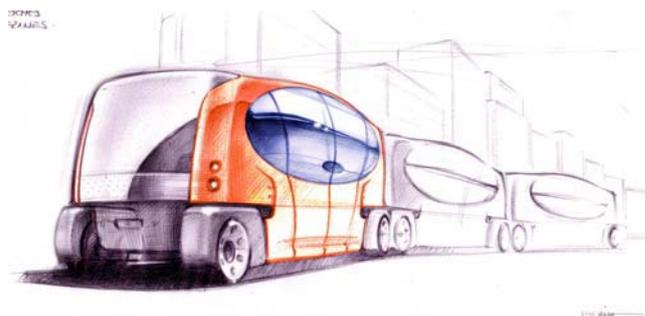


Fig. 2 The concept for multiple unit operation

The actual study was managed by the Helen Hamlyn Research Centre, part of the Royal College of Art, London, and headed by Jeremy Myerson,. Also part of the team was the famous Vehicle Design department of the RCA, led by Professor Dale Harrow.

The work progressed with an in-depth review of the current situation, the many pre-determined global trends and all possible transport solutions. The project team invited a range of experts, from a range of sectors including city and transport planning, the built environment, social

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mechanisms, to ideas workshops to discuss and develop different approaches to the challenges ahead.

From studying these requirements, an idealised system was proposed that used automated vehicles, potentially of variable size, running over the assorted routes. Then a process of back-casting, or retropolation, was applied to discover how this ideal system could be achieved in practice.

It is important to confirm that the *mobility* system was never seen as a universal solution to all the transport challenges in all cities. The characteristics were developed to be complementary to other existing systems based on the various existing road, rail and water vehicles.

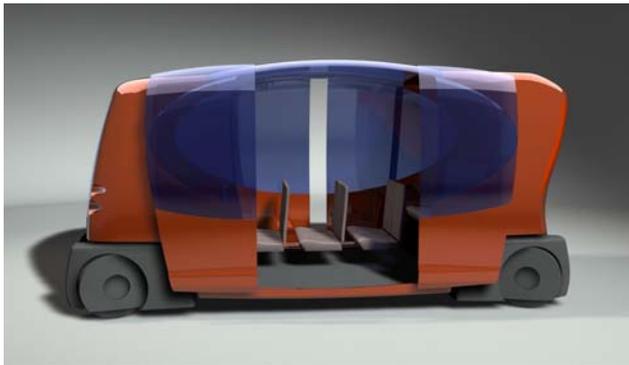


Fig. 3 Single unit in 'taxi' configuration

One fundamental feature of the study was the need for strict technical and commercial realism. The approach had to be able to deliver practical solutions over the time-frame being studied. Therefore any solutions involving exorbitant costs, and those requiring totally new city infrastructures were not pursued. This pre-condition of practicality related particularly to the road and fuel infrastructures.

Together with the RCA team and some ten other project partners, the concept was researched in further detail through 2003 to 2004 and this developed the fundamental concept of the system now being presented.

The *mobility* transport system uses automated vehicles to provide eco-friendly mobility within large metropolitan areas. It has been designed to address the three major challenges of congestion, air quality and energy use, plus deliver the sustainable solution that both the growing population and our shrinking world require.



Fig. 4 Platoon in 'tram' configuration.

The program moved into much greater detail through the next design stage during 2005. The vehicle design was further developed, in much greater detail, into a full 3D CAD virtual prototype as below.

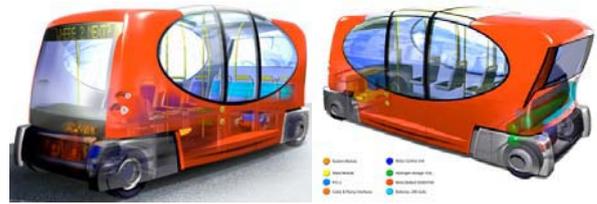


Fig. 5 Bio-fuel ICE and H₂ fuel cell versions

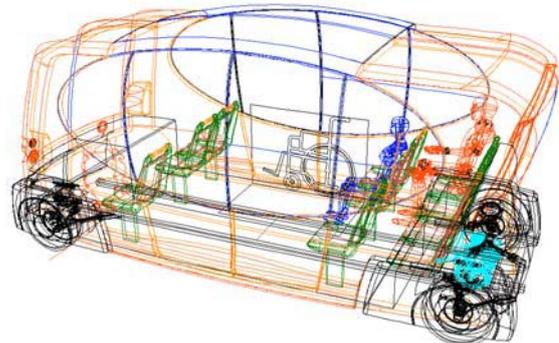


Fig. 6 3D packaging design of virtual prototype

3. VEHICLE DESIGN FUNDAMENTALS

The 5 metre long vehicle offers up to 12 seats including 1 wheelchair space. It can also carry 12 standing passengers, giving a capacity of 24, within the current EU bus legislative regulations, all of this within the length of a premium car. Further, the vehicles can operate in platoons of up to six units giving a total passenger capacity of 144. In this way the system offers unparalleled flexibility in terms of capacity.

The *mobility* design has now entered its third design generation and the work continues with the refinement of all systems, notably the series hybrid drive plus the navigation and control systems. These are covered in further detail below. The actual vehicle is a two axle design, with steered front axle and driven rear axle. The energy converter/generator is front mounted, together with the electronics cooling radiator. The fuel tanks and hybrid battery pack are rear mounted, over the electric drive motor.

The integral frame is aluminium to minimise the vehicle mass, and mounted on air sprung, independent suspension systems. The panels are mainly polypropylene for the vertical panels and self-reinforced polypropylene for the horizontal panels.

The tyre and wheel selection goes entirely against the current passenger trend to fit 'locomotive' size wheels onto small vehicles. The tyres have been selected on a mix of attributes including rolling energy losses and compact packaging space.

Unlike conventional cars, there is minimal brake energy to dissipate due to the controlled 2.0m/s² maximum

deceleration and the regenerative capacity within the hybrid system. Similarly, the system design limits for lateral acceleration are set for passenger comfort and reliable control so the application does not warrant a wide tyre section.

The vehicle unladen mass is 2740kg and the laden mass is 4540kg, giving a payload of 24 passengers at 75kg. The passenger mass fraction at 39% of gross laden mass is lower than some of the usual Capoco bus projects, but this is due to the scale effects with the smaller vehicle.

In early 2006, this latest design configuration was displayed at the North American Auto Show in Detroit. This was part of the Michelin Challenge Design competition to produce new designs to meet the needs of tomorrow. It was awarded an Outstanding Design prize by the Michelin company team.

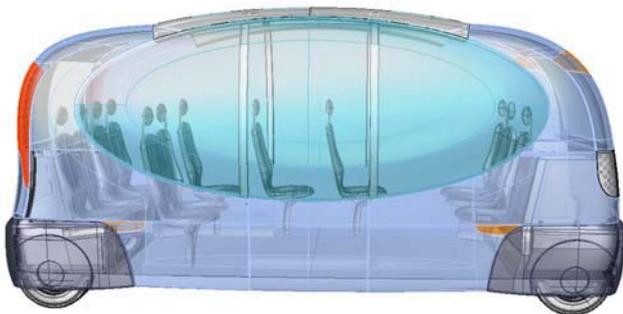


Fig. 7 Ghosted 2006 design configuration

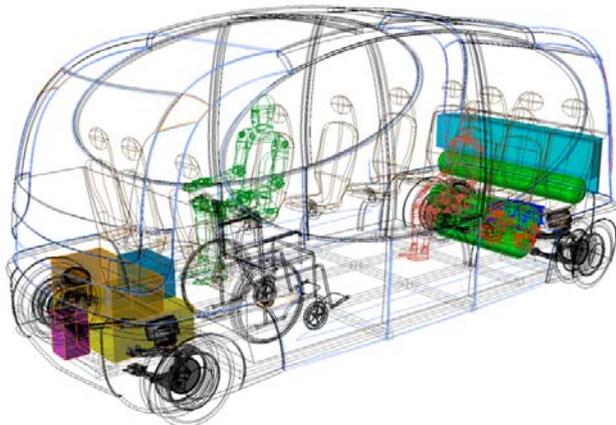


Fig. 8 Wire-frame 2006 design configuration

4. POWERTRAIN

The drivetrain is series hybrid in all versions using a Li-Ion battery. The unit ratings are in the 30 to 40k continuous range. These seem low from a car standpoint, but the 6.7 to 8.9kW/tonne power-to-weight ratios have been extensively proven to be adequate in modern traffic conditions. One significant proving trial could be taken as the fifty year long, successful operation of the famous red London double decker bus. These use a 86kW power unit to propel the 12.5 tonne fully laden bus, so have a rating under 7kW/tonne. These have been totally acceptable in all city operational modes over this long and arduous period.

The energy conversion includes three main options to make the platform future-proof over the coming decades. The first model is fitted with a bio-fuel ICE, the second

format uses a hydrogen ICE and the final configuration uses a low power rating, hydrogen fuel cell. The initial fuel infrastructure requirements are therefore tailored to be ready right now using the existing diesel distribution network.

Both the generator on the ICEs, and the drive motors, use a permanent magnet configuration. Two rear drive motor options are currently being studied. One uses a central motor with integrated controller, reduction gear and differential. The alternative arrangement is using two wheel motors, which aids the packaging considerably. One really important feature with the specific *mobility* design is the effect this wheel motor approach has on suspension performance.

The vehicle has been designed to suit the low speed of modern urban conditions and combines low power ratings, low noise, with increased safety. The vehicle has a low power-to-weight ratio of under 9kW/tonne as described, and the resultant drive motor mass is linked to these lower power and torque outputs. Likewise, the maximum suspension unsprung mass limits are closely related to the wheel ground loads, so there is a quite different relationship between these parameters in this application, when compared to a high power, low mass car approach.

These fundamental factors, relating to specific power and specific cost, apply even more importantly to the whole economics of introducing new powertrain technologies and new fuel infrastructures. Although neither absolute nor linear, the trend effects of unit power and unit costs are quite clear. There are many significant cost barriers to the introduction of new systems such as fuel cells.

Currently, the heavy duty, low volume commercial power units range from USD50/kW for diesel, to USD500/kW for a series hybrid diesel to perhaps USD5,000/kW for a hydrogen fuel cell system. If the costing calculation then factors in a *mobility* power-to-weight ratio of under 9kW/tonne, against 100kW/tonne for a typical car, there is an immediate order-of-magnitude gain on affordability.

However this beneficial effect is compounded by the much higher public transport annual vehicle operating distances and also much higher average passenger load factors. The overall result is an increase in economic viability by a factor of around 300 to 400 times, judged on the fundamental basis of USD/passenger.km.

This essential cost-based approach to public transport, relating to introducing new technology, becomes particularly relevant with the innovative *mobility* concept. Since all current vehicle operating costs are dominated by the driver labour cost, the automated approach can actually finance, even at today's high fuel cell unit costs, the viable application of a hydrogen based, emission free transport system. This point is expanded below.

5. CONTROL SYSTEMS

The greatest challenge during the development of the new *mobility* system is the automation of the vehicle operation. This links the primary control modes of lateral

and longitudinal control, with the associated systems for collision and obstacle avoidance. Also there are the needs of the service operation requiring the land-based supervisory system to control the vehicle routing and scheduling.

This guidance technology, although new, is not without precedent. There are a number of applications across the aerospace, military, marine and industrial sectors. Three examples showing the basic practicalities are shown in Figure 9. The first application is the widespread use of AGV's (Automatic Guided Vehicles) in many factories. The second example is the automated ECT container port at Rotterdam, Netherlands. In this installation there are over 200 driver-less vehicles that have been operating there for a period of 14 years and uses the Frog system.



Fig. 9 Automated operations in factory and dock

The *mobility* guidance system is provided by the project partner, Frog B V, of the Netherlands and it uses three levels of control. The top level is route planning which is similar to the process used with factory AGV's. The required routes are prepared within a computer package essentially similar to a 2D plan view. The second control marries into this by measuring the distance traveled and computes the vehicle position against the route planned in the first level.

The third and final level of control is calibration by checking the vehicle position against the fixed track markers. These markers are multiple magnetic markers embedded in the road surface. The vehicle control system checks the predicted position with this frequent recalibration and any small route corrections are input in a damped manner.

These route markers are quickly and cheaply installed, such that the 'sunk costs' in any route are remarkably low. Routes can be economically installed, modified and moved to new locations, totally unlike any rail based systems.

The vehicles are also equipped with obstacle detection sensors that feature both long and short range sensors. These are based on scanning lasers to provide a detection shield that is linked into the longitudinal or braking system. This will slow, or stop, the vehicle as required, if and when obstacles are located.

The automated service operation is planned initially in closed communities, such as exhibitions and airports and later will deploy in exclusive lanes, like bus rapid transit systems. Once the technology is fully mature, the system will cover the majority of the central city areas. This will allow flexibility in both timetable and routing to offer the best of both worlds – personal mobility within a public transport system.

6. FUEL CELLS

As evidenced at the recent EVS-22 exhibition and conference, there are a number of exciting fuel cell developments being developed. These were particularly evident from the Japanese car manufacturers, which displayed a generally common approach.

This approach is based on a rather static view of the future vehicle product profiles. The two main targets of this approach are a) to offer the same performance as current cars and b) to offer the product at the same purchase price. It is suggested that this approach is flawed when it comes to the rapid changes taking place in climate, energy supply and travel behaviour.

The resultant car style concepts seek to offer fuel powertrains in the 90/100kW band for the probable use by one or two people. Given the very high cost per installed kW of fuel cell systems, this denies the chance for this technology to reach a commercial basis, just when its merits are most needed. The fundamental car approach parameters here combine power-to-weight targets of around 70kW/tonne with fuel cell plant costs currently around USD5k/kW.

It has already been recognised that the potential application of hydrogen fuel cells is more readily adapted to public transport system approach. This centres on the predictability of both route and daily mileage so that the duty cycle is clearly defined.

In the case of city transport, this then extends to the refuelling aspects where the vehicles are linked to a certain operating area and base depot. This frees the operating environment from all the spontaneous and unpredictable duty cycles linked to the private passenger car. The other great gain is the requirement of only 12 to 15kW/tonne in terms of power unit.

The *mobility* approach is clearly linked closely to the public transport scenario. The system enjoys all the benefits of a fixed area of operation and closely defined duty cycle.

However, certain critical aspects apply that make the new approach to be able to offer a fuel cell powertrain on a truly commercial basis. The first is an even lower power-to-weight where a low speed, low noise and high safety approach is adopted. The system has been configured for a laden kW/tonne ratio of 6.7 (continuous) to 11.2 (intermittent).

It is likely that any car specifiers would find implausible that a city vehicle can operate credibly at below 7kW/tonne. This is not the case. Many city buses, including the famous red double-deck bus as mentioned above, have operated very successfully in dense London traffic over this period with a specific power of only 6.8kW/tonne.

The hybrid approach is battery intensive so allows both a smaller fuel cell unit and frequent fuel cell part load operation for better stack efficiency.

There are further commercial advantages when the aspect of automation is included. If one looks at the operating costs of a current bus, it is the driver labour cost that dominates at some 50 to 60% of operating costs, way ahead of fuel, tyres, glazing, servicing etc. With

automation, we get an affordable, urban mobility system, emitting only water and sustainable on both economic and environmental grounds.

Reviewing these metrics, we are led to very profound findings on specific costs. The current 'concept car' approach leads to a coarse first costs for the power-plant currently around **USD350k per user**. The net effect of the **mobilicity** approach is this fuel cell system first cost comes down to only **USD6k per user**.

If the duty cycle calculations are further developed to include typical passenger numbers, annual operating hours and vehicle life, the appeal of mobilicity is even greater. On current fuel costs, for the passenger car approach, we can get over **\$6 per passenger mile** just on power-plant purchase price alone. This compares to values down to **2 cents per passenger mile** for the **mobilicity** approach. With **mobilicity**, this low cost basis can actually be funded by the savings in the driver costs and so offer the ideal solution of affordable, zero emission city travel.

7. SYSTEM OPERATIONAL PERFORMANCE

As mentioned under the control and navigation system section above, the hardware on the ground is very limited. The main route control is computer-based and the system can use any existing hard surfaced roadway. However it is planned that the systems will be largely exclusive lane to enjoy the benefits of free traffic flows and to minimise the interaction with other vehicles and pedestrians.

It is hard to imagine that any new lanes could ever be found in the existing city centres, clogged with traffic. However, the bus industry, in hand with various city authorities, has recently proven this can be achieved. The roll-out of Bus Rapid Transit, or BRT, systems around the world have demonstrated perfectly that changes can be achieved in a short time and at low cost. The BRT system use dedicated bus-ways, rather than the usual bus lanes, that are prone to illegal disturbance from other traffic flows.



Fig. 10 BRT systems around the world

However, it is planned that some civil engineering will be required to optimise the new **mobilicity** systems. As well as the **mobilicity** lanes, new stops will be required and the system will need adequate information systems to inform passengers of the system status and current service level.

Again these new facilities have the advantage of being able to be phased during their installation due to their low cost and speedy installation. Also partial systems can be operated as new neighbourhoods are developed. This contrasts strongly with rail systems that are 'all or nothing' as any train or tram is left stranded if gaps are incomplete through certain areas or interchanges.

The system capacity is vitally linked to the much higher effectiveness of public or collective transport, compared to private or individual transport based on the passenger car.

A collective public system is essential to greatly reduce the demands of both road space and energy. The three images below show the same total number of travelers, of 150, in three different modes. Whereas the car approach immediately results in total system blockage, the bus or tram-style platoon leave huge amounts of space. As mentioned above, the first reaction is how can any new transport system find the space to operate? These pictures dramatically show that integrated, high capacity public transport systems can be installed, PLUS wider sidewalks PLUS bicycle lanes PLUS tree lined lane dividers.



Fig. 11 Road space utilization, all with 150 people

It is informative to compare the **mobilicity** approach with what is widely regarded as a successful attempt at a city car design, the Smart Fortwo. One interesting aspect about the car is it is only 2.5 metres long, but carries only 2 people so has a lower passenger linear density than most other cars that achieve around 1 person per metre. So the **mobilicity** vehicle is exactly double the length of the tiny city car, but offers 12 seats and 12 standing places. Interestingly, the **mobilicity** has the lower total power rating.

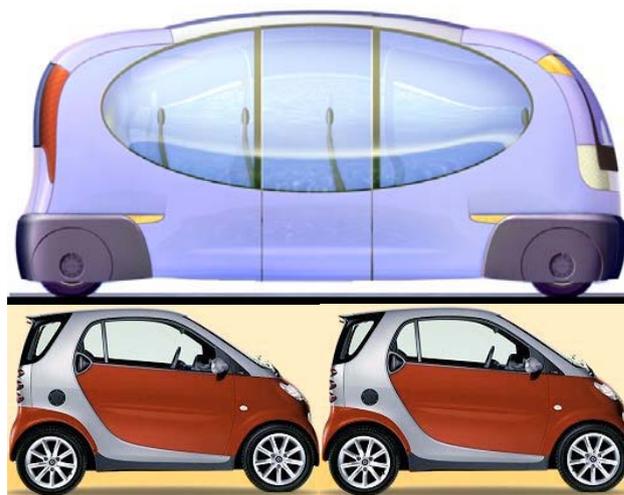


Fig. 12 5m **mobilicity** and 2 x 2.5m Smarts

Three traffic scenarios were studied, all based on the usual metric of passenger capacities per lane per hour. This is the same as per direction per hour. Three vehicle conditions were analysed. All the cases operated with the same time-based running clearances or headways between

the vehicles, which varied with vehicle speed.

The first case was the Smart car operating in the most frequent private car mode of 1 person aboard. The second case was individual *mobility* vehicles running with 12 seated passengers. The third mode was *mobility* vehicles running at full seated and standing capacities, and also operating as a six vehicle ‘tram’ platoon. This last condition would be for heavily-used arterial corridors or at major city traffic nodes.

The relevant lane densities are shown in Figure 13 in the form of passenger per linear lane metre. As expected, the car approach is limited to fairly low values due to first the poor vehicle packaging, but also critically the multiple inter-vehicle gaps when running at higher speeds.

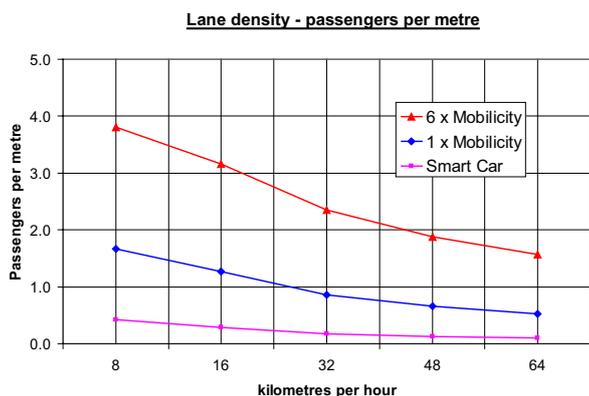


Fig. 13 Passenger densities per lane metre

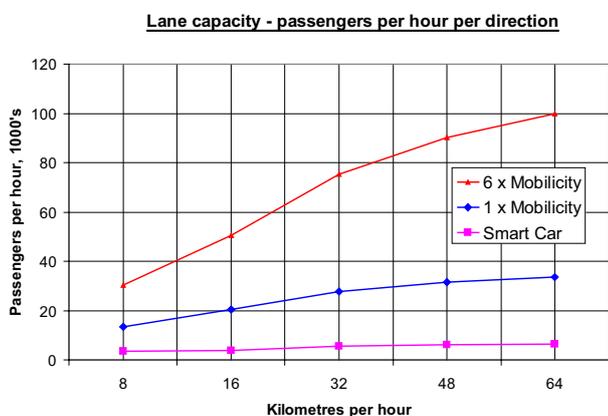


Fig. 14 Passenger flows per lane per hour

This effect is more marked when shown as the fundamental passenger capacities per direction per hour as Figure 14. The car again is strictly limited to very low values and it is this basic characteristic that currently clogs up our cities. Even if these car values are acceptable on straight road sections without junctions, the values will not provide enough flow at bottlenecks and where routes converge. The two *mobility* configurations offer very high capacities that rival rail-based solutions. It is recognised that these high values will not be achieved over the complete routes, but it demonstrates the potential for the system to absorb

very high passenger flows within a single lane, where required by the city layout.

8. FUTURE PROGRAM

The *mobility* program is now reaching the final stage of the research and development activities. The ongoing developments will be displayed on the project web site on www.mobility.org. The prototype stage will be the next phase with the construction and testing of two vehicles. These will be assessed in the controlled environment of vehicle proving grounds to validate the various system functionalities and ensure their safe and legal operation.

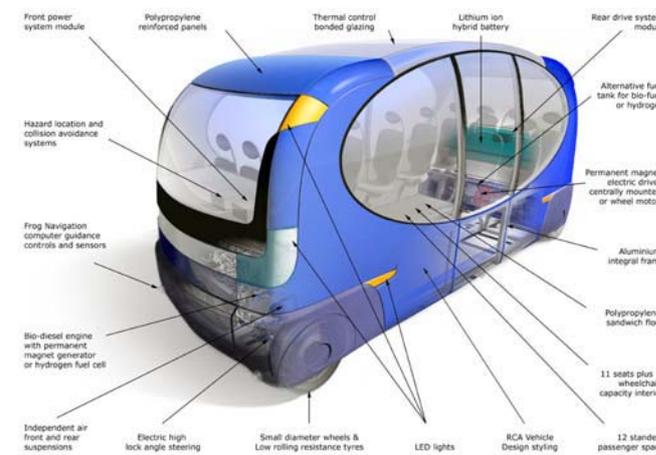


Fig. 15 Cutaway view of latest vehicle design



Fig. 16 *mobility* in city based automatic operation

The subsequent phase is a batch of six ‘seed’ vehicles to operate a trial service at a selected exhibition centre. This service will be used to ferry visitors on a shuttle service between the halls and the car parking areas. Further applications are currently being planned for airports, national expos, large sporting installations plus new systems being integrated into new retail and residential developments. The key aspect here is the vital preparation for all our tomorrows. The world is changing rapidly and

transport systems will need to change rapidly as well. It is essential for both everyday life, and the global economy, that personal mobility is maintained within the huge city complexes of the modern world. Likewise, it is equally essential that the remaining scarce energy resources, limited road space and clean, healthy air cannot be all consumed, as it is today, by the use of the private car, which both uncontrolled and uncontrollable.

BIOGRAPHIES



Alan Ponsford founded Capoco Design in 1977 and is the company's Design Director. He received a B.Sc. Honours degree in mechanical engineering from Imperial College, London in 1972.



Merih Kunur received an MPhil from the Royal College of Art for his thesis on inner city transport and mobility issues within London and exploring new directions of individual urban journeys in 2020.