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- e-carrus -

A new Clutch-on Hybrid Electric Vehicle (CHEV) and Application

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Summary

e-carrus (Latin --> wagon) is overall a new mobility concept for urban regions, using vehicles in a very new way of hybridization. A conventionally ICE-driven car with a coupling device will be pushed by an electrical driven two-wheeler (imagine! A kind of blown-up Segway). By this combination of a conventional car and an electric wagon a new type of hybrid vehicle is defined. The application is only used in urban regions, finally with fully automatic coupling and autonomous operation of e-carrus before and after coupling. Business models for shared economy have been developed. Technology and details will be presented.

Keywords: business model, city traffic, HEV (hybrid electric vehicle), ZEV (zero emission vehicle)

1 Introduction to the **e-carrus** Concept

A variety of forces will change the future mobility. Legislation, CO₂ regulations, technological advance for conventional, electrical or hybrid vehicles, basic need of individual mobility, new trends in living, environmental thinking but also budgets and cost have a notable impact to future mobility solutions. The electric mobility is one pillar to reduce CO₂ and other harmful emission. Industry and science achieved a new level of performance and quality with new developments of EVs and other electric driven vehicles like HEVs. Parallel to advances of these EV and HEV technology the improvement for conventional driven vehicles is an ongoing process and alternative fuels like CNG or LNG are again in discussion. Nevertheless, it is well known that both concepts couldn't substitute each other. Combustion driven vehicles have their strength in long distance travelling and EVs their big advantage of zero emission in urban and inner city traffic.

The **e-carrus** concept tries to combine the best of both. Keep the combustion driven vehicles in their invincible domains of usage for long distance, interurban or high performance driving and provide a concept for this majority of vehicles for zero emission driving in cities or municipalities with adequate performance and economic battery sizes. The **e-carrus** concept comprises a new technical solution for different fields of application as well as related business models.



Fig. 1 example for e-carrus configuration

The technical dimension of the new concept in a basic configuration level is a compact, electrical-driven trailer-like vehicle which will be coupled to a normal car or van as outlined in Fig 1. The **e-carrus** - used in urban regions and zero emission zones only - pushes the conventional car up to a max appropriate speed of 70km/h. The driver controls the **e-carrus** using the normal control-units in his car like accelerator or brake pedal. The system uses standard car trailer interfaces so modifications for the cars are very low. For the advanced configuration level, **e-carrus** is a semi-autonomous **traffic-robot**. The coupling and manoeuvring of the traffic-robot should be fully automated for highest customer satisfaction.

An example for a first application will be the use for urban delivery enterprises challenged by upcoming Zero-Emission-Zones with restricted access for conventional vehicles and existing conventional fleets. A really disruptive application will be the full integration of the advanced **e-carrus** traffic-robot solution in an urban mobility concept providing this as a service to all - private car users, commuters or enterprises. Municipalities could install the zero emission zones with less implementation barriers, offer a solution to residents and car owners and earning a lot of money by selling the whole energy for the mobility.

The basic principle for the different business models is the shared economy approach, using the expensive drive and battery system closed to 24/7 and addressing the whole world wide existing fleet of conventional driven cars as customer. This concept is to see in parallel to all the EV and HEV activities. It could be an eco innovation for combustion motor driven cars with strong leverage to fleet CO₂ targets because it's an application for the majority of vehicles. It is also an enabler for authorities to continue establishing emission limited or restricted zones in cities or municipalities for better air quality and living standards within the cities.

This challenging idea should be investigated in several research projects with different focus. This paper should give an overview about the idea and shows some results from the technical feasibility study.

2 **e-carrus** Applications

2.1 System Design and Car Interface

The **e-carrus** traffic-robot has an electrical drive similar to fully electrical vehicles (FEV). Due to the specific application in a city or a Zero-Emission-Zone the drive is much smaller compared to a FEV. This could be shown at the Speed-Traction-Diagram for a typical car application:

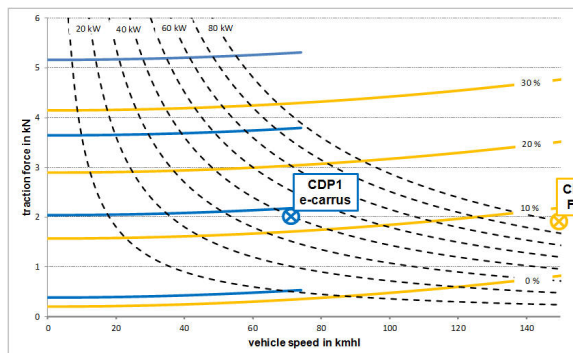


Fig. 2 System design points

The diagram shows in orange lines the traction forces for different slopes (0% ... 30%) for a conventional vehicle or a FEV with same design. Per definition it was assumed that the weight of FEV and conventional vehicle is the same. For the combination of **e-carrus** together with a conventional car the traction forces are shown in blue lines. Looking to critical design points CDP1 and CDP2 at minimum climb ability at max speed, it is obvious that the **e-carrus** system design needs about half the power of a FEV system design.

The limitation to the urban usage with a max-speed of up to 70 km/h allows a compact design with a medium power of 40kW, sufficient for normal acceleration. The **e-carrus** concept is a totally different application. The necessary driving range is much lower than in a FEV-application and achievable with today battery technology. However, the system will be designed with a large battery, fitting to a max weight regulation for trailers of 400 kg and providing sufficient traction force with standard tyres. A 200 kg battery with 20 kWh capacity will provide a useful driving range of appr. 50-200 km very strongly depending on the size of the car using the traffic-robot.

A necessary feature is a variable drawbar which is automatically adapted to the operating points. The distance between robot and car should mainly be closed to zero to safe traffic space (e.g. standing at traffic lights). Only for specific operating modes the shaft is used as lever (e.g. for stronger acceleration) or has to be adjusted for curve driving:



Fig. 3 - Trailer-like e-carrus with conventional vehicle during acceleration (gas engine off)

Combustion Vehicle Interface

The mechanical interfaces are simple the standard trailer clutch which is available for nearly all known cars. However, the existing and future conventional car needs some new interfaces, largely in the control system. It is necessary to modify the control strategy in this way that the car network signals could be used by the **e-carrus**. Further auxiliary systems in the car (e.g. climate, infotainment) have to operate when the **e-carrus** is coupled to the car. Today's vehicle architecture and new functions like "Start-Stop" are a very good basis for a 'simple' adaption of the combustion vehicle. A Start-Stop function addresses all affected aggregates and control units in the right manner. The Start-Stop state machine has to be extended by an additional state – "rolling with engine off". Technologically this 'sailing-mode' is a new software function introduced today as eco car innovation.

The most affective impact will be the usage of the accelerator pedal as throttle control for the **e-carrus** during the combustion engine stop mode and a variety of safety issues have to be considered. The effort for this adaption of combustion driven cars is very low compared to the OEMs challenge of platform hybridisation. An additional display screen in today's instruments is effort but no specific challenge.

A discussion about several comfort functions like the heating or cooling of the car during electrical operation is expected. For this we refer to the problem solving for EVs and plug in HEVs. We assume to use similar solutions as used for these types of cars.

Providing this software interface in future cars is a clear large volume enabler for this idea. Motivation for car makers is possible with the eco incentives for the fleet defined by the international emission laws are overcompensating this development effort. For small volume and retrofit of existing cars, interface control units have been developed for several HEV conversion vehicles like demonstrated in [1].

2.2 e-carrus basic Application

The **e-carrus** concept in general comprises a new e-mobility service for conventionally driven cars with a new special electric vehicle design. It is planned to offer a zero-emission moving service for conventional cars and vans - a service in urban regions and Low-Emission-Zones with restricted access. A private car user, commuter or delivery transport enterprises will be able to drive into city zones with access restriction with his normal car or van.

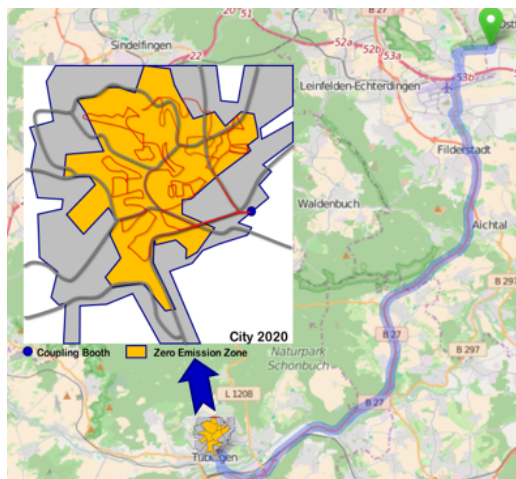


Fig. 4 e-carrus for logistic fleet

For a first basic application the **e-carrus** vehicle should be manually clutched to the car like conventional vehicle trailers. This makes sense for a small volume fleet use and a business ramp-up. Interesting application examples are city delivery services and last mile logistics. Often the big logistic service providers have transshipment points far outside the cities as outlined in Fig. 2. For the long distance to the city the conventional driven delivery van is used with today's comfort and speed (blue track on map). At the city border the **e-carrus** is clutched to the van and then the distribution will be fully electric driven (red tracks in zero emission zone).

The fleet operators will have further advantages. E.g. it could bridge the years without really cost effective EVs and for a mixed fleet the whole fleet and logistic mission planning is more complex.

2.3 e-carrus advanced Application

The main target for the use of **e-carrus** are applications based on the advanced configuration level as traffic-robot. As a traffic-robot many additional functions are added to the basic driving function. To develop the understanding of the advanced application, the following paragraphs show first selected features, then the process of coupling and finally the whole concept for urban mobility integration. The key features of **e-carrus** as traffic-robot are:

Automated Coupling: Fully automated mechanical and electrical coupling of the shaft to the trailer ball with an advanced coupling system. Mechanical coupling with a shaft side actuator gripping the standard trailer-ball at the car. Electrical wireless coupling includes CAN connection and powernet connection integrated in the shaft side actuator and a simple receiver/transmitter adapter plugged into the trailer socket

of the car. It is essential to use the well established trailer ball coupling interface. Many of today's cars are equipped with this automobile accessory or are easy to upgrade. In this case a minimum of car modifications are necessary.

Car 12V supply: The robot supports the 12V battery system in combustion engine off mode. Similar to State-of-the Art Hybrid-EVs the comfort functions have to be available also for the operation in engine-off mode. Full comfort is possible with electrified HVAC and PTC-heating, provided in many cars nowadays with a clear increasing equipment rate.

Balance Control: The **e-carrus** vehicle needs to be operated manually or automated for the un-clutched use-case – e.g. changing from on to the next customer vehicle. The two-wheeler on one axle has to be balanced as known leisure vehicles like a Segway®.

Autonomous Manoeuvring: One of the important features is the autonomous manoeuvring. For a large volume implementation and an absolute necessary user comfort, the manual hook-up of the drawbar as described in the simple basic application is not suitable. With today's automotive and robotic technology, it is possible to manoeuvre the traffic-robot fully autonomous from one car to the next or to necessary charging hubs. This fully autonomous operation is the reason why **e-carrus** is classified as a traffic-robot. Details will be described in the following chapters.

Drawbar or shaft control: The **e-carrus** drawbar needs to be controlled in length and height according different operational situations: - Adjustment of the shaft level height to the right level of the trailer ball with shaft level actuator. - Shaft length reduction for cruising and e.g. stop at traffic lights for traffic space reduction. - Kink angle control supported by shaft control for safe curve driving and vehicle-robot collision avoidance. - Active length (and level) control of shaft depending on throttle value for comfort reasons (pitch control as described in chapter 4 in detail).

Further functions as shown in the following bullet-point list are necessary or an option: - Sensor system for automated driving and functions like visual detection of trailer ball level. - Vector control of trailer ball force for all dimensions. - Manual manoeuvring is necessary for different use-cases like service or specific customer demand. A forceless manual manoeuvring will be supported by traction drive, balance control and shaft control e.g. with an intelligent sensor grip. - Regenerative braking control. Braking force distribution like P4 Hybrid application supported by shaft force sensor. – Stand-by charging is planned on a specific charging bed for several equal traffic-robots. Inductive charging from bottom side controlled by infrastructure.

2.3.1 Autonomous operation for **e-carrus**

The coupling of the traffic-robot to the conventional car should be fully automated for highest customer satisfaction. This “coupling” is not only hooking-up the drawbar to the trailer ball with an intelligent actuator. It is more. This coupling process also comprises the manoeuvring of the **e-carrus** vehicle to the back of the car. The overall autonomous manoeuvring is best to demonstrate with the following drawing.

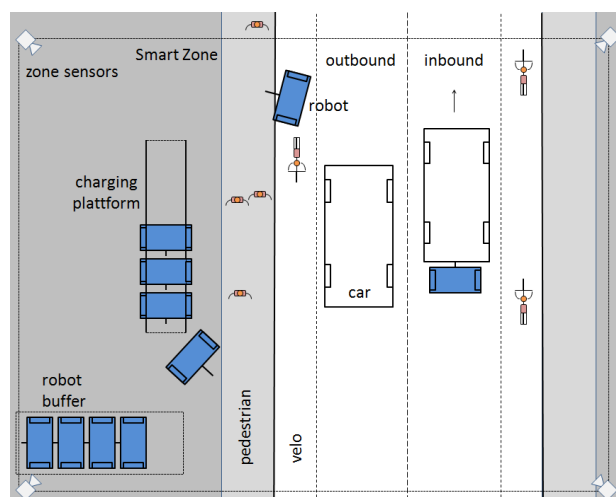


Fig. 5 Coupling booth for traffic robots

The figure shows a schematic of a road section with inbound and outbound traffic. The coupling and decoupling of this fleet of robots to cars should be fully automatic. High turnover, flexibility, low invest for infrastructure and finally the absolute essential comfort for the user are the main arguments for this high sophisticated attempt. The outbound driver leaves the Zero-Emission-Zone and the **e-carrus** vehicle will be un-hooked and drives back to the charging platform or an inbound car/customer. Vice-versa the inbound driver ordered the service and a traffic robot drives from the platform to the back of the car. Simpler variant of this manoeuvring is with stopping cars e.g. at traffic lights; really sophisticated will be this use-case on the fly with moving cars.

The example layout shows a “coupling booth” which covers a section of public road with full access of different type of vehicles and people. A group of traffic-robots has to manoeuvre in between cars, charging

stations, coupling traffic road-lines or storage buffers in very different public environment. Typically, the more complex situation for autonomous driving. This “coupling booth” should be designed as a smart space with integrated sensors in the infrastructure (e.g. cameras). Interactions between the robots, vehicles, road users and the infrastructure, are monitored in the smart space and should be used for improvement of quality of navigation and safety of all road users including pedestrians or bicyclists.

The infrastructure in this coupling booth includes a flexible charging platform and a robot stock as demand buffers. Charging platform and robot buffer are simple cubes for easy installation. The **e-carrus** vehicle will drive over this platform for inductive charging with coils in the bottom of the vehicle as well as easy stabilizing with balance control-off mode.

2.3.2 Urban large scale Implementation

The **e-carrus** traffic-robot will be used in urban areas, low emission zones, in city regions or other areas with emission reduction issues. The following schematic map shows the example of an undisclosed city in 2030 and its zero-emission-zone with a large number of coupling booths for the traffic-robots.

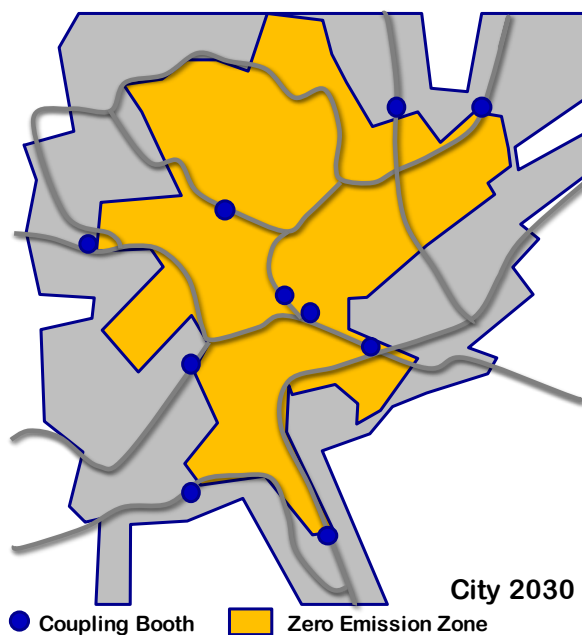


Fig. 6 City with several coupling stations

It is assumed, that future cities have new or enlarged zones with a zero emission regulation or access restrictions as shown in the left figure. The coupling booths for the traffic robots are dedicated zones located at city access road and big parking spaces in the city. The robots are available at the fully automatic exchange stations but could be used individually within the whole city zone. The idea is that a city together with the local public transport provider offers this service. The booking of the traffic-robot should be integrated in the ticketing system for public transport.

The customer and end-user saves the direct cost for the gas and the access toll or a part of the toll plus the investment cost in a second car. He pays for the electric energy and a contribution for the usage of the Traffic-Robot. The fee for the usage of the service could be on an acceptable level for the customers. The 24h service with a highly effective operation of the robots for many different customers and the integration in a hybrid business model enables interesting offers to the customers.

Other possible areas of operations, not discussed in this paper, are dedicated residential areas or road sections with high pollution and the need of low invest solutions.

3 Business Models for **e-carrus**

The **e-carrus** idea addresses in general worldwide all users of conventional vehicles which are affected by current or future emission regulations in urban areas. The use of **e-carrus** is possible for all private or commercial car owners, individuals or fleet owners, and it is independent of the type or brand of car¹. Auxiliaries like a trailer ball and the electric connection interface to the car are necessary but standard and in use or easy to upgrade.

Taking into account that only a share of the overall vehicles will use the system, the overall estimates for a market volume are in the range of several hundred thousand units in Europe. The multi use of the system on demand allows millions of conventional vehicles a zero emission driving. However, the real volume depends on a wide range of impact factors. There are many forces in a market influencing the success of a technological development.

¹ Trucks and larger vehicles are also possible but not explicit evaluated in this document.

3.1 Market Forces

For the **e-carrus** traffic robot idea we have looked for driving forces and competitive forces influencing the market development from other sides. An overview is given in the following chapters.

3.1.1 Market driving Forces

Many municipalities have established or want to set-up traffic limiting or restricting zones. They are mainly driven by air quality targets, reducing congestion, increasing the overall liveability and so on. The European Commission has an Action Plan on urban mobility to encourage and help local, regional and national authorities in achieving their goals for sustainable urban mobility [2]. The different access restrictions and regulations address passenger and freight traffic, they consider the emission standards (e.g. EVs), congestion situation, time slots etc. and they use different instruments for billing and fining [3]. A core problem for acceptance is that private car users and commuters as well as freight distributors are bothered by access restricting zones. They need or want to drive in and out of the restricted zones with their own existing car and without invest in additional or expensive zero emission vehicles.

→ Further dissemination of access restricted traffic zones needs a service or a technical solution for conventional car owners, commuters or enterprises like **e-carrus** ←

European Union legislation sets mandatory emission reduction targets for new cars [4]. The automotive industry uses new technologies for the new generation of cars - from lightweight design to new generations of combustion engines. But with incremental innovations the capabilities are limited. It's nearly impossible to come down from 133 gCO₂/km (Ger, 2014 [5]) to the 2020 target of 95g CO₂/km and further achievements need again much higher invests [6]. If the average CO₂ emissions of a manufacturer's fleet exceed its limit value in any year from 2012, the manufacturer has to pay a penalty, the excess emissions premium for each car registered (E.g. breach of 1 g and 2.5 Mio Fleet = 238 Mio. Euro). But manufacturers can be granted emission credits equivalent to a maximum emissions saving of 7g/km per year for their fleet if they equip vehicles with innovative technologies, based on independently verified data.

→ Carmakers can reduce the fleet emission with **e-carrus** Eco-Innovations to achieve EU Targets ←

3.1.2 Competitive and supporting Forces

Today's research and development in the field of the new wave of electro mobility is focused on designated areas. Several national governments in the EU and worldwide as well as the European commission push the technology and business in a variety of well funded initiatives. The targets for a future market share of new Electric Vehicles (EV) are challenging. Each Nation announces ambitious targets for the local industry (E.G.: German target 1 Million vehicles in 2020 [7]), but it is foreseeable that real volumes will be lower (1. Jan. 2015 overall 126.702 units EV and HEV [8]). Several studies for the future trends in worldwide vehicle markets are published by carmakers, large automotive system suppliers and well known consultancies. In 2020 the overall market for passenger cars and light trucks is about 115 million units (see [9], [10])². The share of EVs is estimated with 2.5 m units, for plug-in Hybrids 3.1 m units and for all other Hybrids 6.5 m units. That infers that about 90% of the vehicle market has no benefits from the strong efforts in the field of electrical driving.

→ Political focus on electric vehicle activities only with small leverage in worldwide vehicle market, **e-carrus** could address all existing vehicles world wide ←

Today's FEVs (fully battery electric vehicle) from different carmakers support the electrification of transport but only with small series roll outs compared to typical production volumes. The current generation of performance in terms of range, power and energy efficiency of FEV does by far not meet customer's expectations on a broad basis [11]. It will require tremendous efforts in improving these FEV concepts to get competitive vehicles that are reliable and have similar performance attributes as nowadays conventional vehicles. The physically and chemically limited performance of the battery is an accepted argument explaining that FEV cannot replace conventional driven vehicles.

→ FEVs cannot replace conventionally driven vehicles but **e-carrus** could make conventionally driven vehicles to zero-emission vehicles in relevant urban applications←

² Both references from the same author Bosch but 2010: 19 Mio vehicles worldwide with electrical drive have been reduced to 2012: 12 Mio. Units

In addition to the FEV solutions the carmakers force the development of PHEV (plug-in hybrid electric vehicles). The PHEVs have some slight advantages in emissions and performance against conventional vehicles, but they have to pay for this with an appreciable additional load and a tremendous system complexity. For electrical driving in zero emission zones it is necessary to carry a big battery and the electrical drive – a burden especially for interurban or motorway travel. Hybrids have shown a small fuel and emission reduction in standard driving cycles but in real world usage the algebraic sign could make a turn. Carmakers have an unsolvable dimensioning dilemma for hybrid vehicles.

→ PHEVs advantages in cities are subverted by interurban or long distance driving ←

3.2 Key Stakeholders

- **Municipalities, cities, public transport operators and local energy provider**

Municipalities are the key enabler for the proposed concept. The **e-carrus** concept is able to reduce the societal and political obstacles while introducing city access restrictions. Offering this solution, they have to have an answer to all of the people which want to stay with their combustion driven cars. Due to their empty coffers they might be interested to open a new source of income. So cooperation with them is very useful. Local energy providers often owned by the municipalities have a further big customer for local electrical energy consumption.

- **Carmakers**

They should have interest in this type of easy electrical driving in urban regions and provide a simple software interface for better system integration. An early partner might have some competitive advantages if the volume increases.

But more important is a chance to a very **big economic advantage with count against the “Eco-Incentives”** defined by the European emission legislation. Carmakers have the problem to achieve emission targets of 95g CO₂/km (2021) with an **economic solution** [4]. (If the average CO₂ emissions of a manufacturer's fleet exceed its limit value in any year from 2012, the manufacturer has to pay a penalty, the excess emissions premium for each car registered; E.g. breach of 1 g and 2.5 Mio. Fleet = 238 Mio. Euro). Manufacturers can be granted emission credits equivalent to a maximum emissions saving of 7g/km per year for their fleet if they equip vehicles with innovative technologies, based on independently verified data. This could be the **software interface for the e-carrus traffic-robot** to enable the complete fleet to drive emission free in urban regions.

- **(European Commission)**

A political support in introduction of city access limitation and a kind of standardization of the access restriction schemes is helpful for the long term success in Europe. Further the support of the eco-incentives for carmakers integrating the interface in conventional cars helps to achieve the European long term targets.

3.3 Market Size

The **e-carrus** application was subdivided into a basic and advanced solution. However, for the business the basic application is only an introduction step for the advanced solution. So overall market for advanced application are the basis for the following aspects.

Key overall market is to see worldwide all users of conventionally driven vehicles affected by the transport whitepaper targets mentioned above. Market volume estimate could be done with different calculation models. The following figures should give an impression about the dimensions and show a first rough estimate for Europe.

- Worldwide existing volume of cars (incl. truck + bus) is appr. 1.000.000.000 units.
- Worldwide production estimate 2020 for passenger cars and light trucks: 115 Mio. units, the part of EVs is 2.5 Mio. and plug-in Hybrids 3.1 Mio. ([10])
- German target published by the "Nationale Plattform Elektromobilität" [7] with 1 Million vehicles in 2020. Each Nation worldwide has similar targets. Real volumes will be lower.

Maximum Market Estimate for Europe

The market for **e-carrus** is defined by the application in restricted zones. A study about the Access Restriction Schemes [2] mentioned in 2009 a sample base of 417 Cities in Europe with a majority of ARS. A

good database to estimate the number of directly affected vehicles could be found in the annual reports of the London ARS [12]. They present a nearly constant traffic flow over the years. The measured "Traffic entering the central London charging zone (across all inbound roads), during charging hours was roughly 120 000 cars + 50 000 Vans 15 000 Lorries and 60 000 taxis. So roughly 2-3% of the London citizens are affected by the London ARS daily. A projection of this percentage to Europe with over 750 Mio citizens living more and more in cities, results in roughly 20 Mio. of potential customers are affected by ARS daily after overall introduction. If 10% decide to use the **e-carrus** as a smart solution for their access problem **2.000.000 Traffic-Robots are necessary to satisfy the European market**. A competent estimate about the growth rate into this new market does not exist. It is part of the planned feasibility study.

Further Markets

- A worldwide application of **e-carrus** is possible (not estimated up to now).
- Fleet owners will have big advantages – most fleets need conventionally driven cars. Additional electric cars are expensive, need an own fleet management and logistics. A cheaper way is to keep all the conventionally driven vans or cars and equip them all with the simple standard interface for **e-carrus**.
- Upcoming residential areas with access restrictions as known from several regions in the US.

The **most useful market segment for initial introduction** of the new solution is probably a large fleet operator within Europe in a first demonstration municipality (e.g. a parcel service, post, public utility)

Most important market barriers to be overcome to realize commercialization are:

- The city access regulations have to be introduced on a broadly base
- End-User acceptance is necessary – (Marketing is a very important issue – GenY effects possible?)
- Carmakers lobby need to be convinced about the idea (see cooperation with key stakeholder)
- European Commission need to keep the low emission targets (Things like German chancellor Merkel intervention to postpone the 95g CO₂ target to 2021 were not positive!)

3.4 e-carrus Business Model

The market for this product is emerging with the upcoming urban access regulations. All affected tional car users are potential customers as later shown in the market volume estimate.

Price finding is known as a difficult issue; the more the pricing benefit for the end user, the lower the margin for the provider. The **main benefit for the end user is the accessibility to cities but acceptance is expected for similar cost** for driving in urban regions. The right table shows some draft figures driving cost for small and large cars. On this base a weighted price could be defined with appr. 12€/100km (Table 1).

Scenario	Combustion Car	
	Low	High
Energy	6l/100km	12l/100km
	1,2€/l	1,6€/l
Cost	7,2€/100km	19€/100km

Table 1 – Customer cost based pricing – defined: 12 €

The business model is only a lease or rent system which is useful for shared investments and the unique selling point is self-evident. Other benefits which are lower investment for second car or more expensive alternative vehicle is not evaluated here. End-user do not think in this dimension. Savings in investments are more an economic benefit considered by fleet owner or enterprises.

For a single robot a simplified gross margin contribution is presented in the table 2 to the right. Prizes for energy, degree of utilization, maintenance (including exchange of battery after 5 years), are simple estimates to get a picture. Typical driving range per day is roughly the same as for urban busses (250-300km, 18h) [13] and so far a conservative estimate. This conservative approach is similar for the other factors like utilization per day and per year or for the high consumption of 30kWh/100km which is at the upper limit for very large cars or winter time.

With a single **e-carrus** vehicle invest of 10.000 € and used in public transport a contribution of nearly 4000€/ year is possible.

Revenues		
Customer Price	12	€/100km
Average Speed in City (Energy Basis)	20	km/h
Degree of utilization / day	50%	h/24h
Average driving distance/day	240	km/d
Revenues by Usage per day	28,8	€/d
Degree of utilization / year	80%	
Usage - Revenue / a	8410	€/a
Adverts	500	€/a
Monthly/Annual subscription	500	€/a
Robot Revenue / a	9410	€/a
Cost		
e-carrus System	10000	€/pc
Depreciation Period	5	a
Depreciation System / year	2000	€/a
Maintenance / Wear	1000	€/a
Energy Consumption / 100 km	30	kWh/100km
Energy Cost/kWh	12	ct/kWh
Energy Cost / d	8,64	€/d
Utilization /year as above	80%	
Variable Cost / year	2523	€/a
Overall Robot Cost / Year	5523	€/a
Contribution margin / year	3887	€/a

Table 2 single e-carrus contribution

However, it is not easy to understand the system behaviour and the impact of many different geometric parameters. There are several design parameters which should be investigated in regard to the impact to the pitching. For this sensitivity analysis the selected parameters are: the length mounting position of the drawbar, the position of the centre of gravity of the **e-carrus** vehicle, the mounting position of the trailer ball and finally the size of the wheel. The results of the impact analysis are shown in the following table.

l_D [m]	$\Delta\varphi$ [degree]	h_D [m]	$\Delta\varphi$ [degree]	h_{SP} [m]	$\Delta\varphi$ [degree]	z_{K0} [m]	$\Delta\varphi$ [degree]	r_A [m]	$\Delta\varphi$ [degree]
0,5	2,56	-0,25	1,19	0	1,32	-0,25	2,75	0,1	-1,11
0,75	1,61	0	1,19	0,25	0,96	0	0,74	0,2	0,03
1	1,17	0,25	1,12	0,5	0,63	0,25	-1,62	0,3	1,17
1,25	0,92	0,5	1,01	1	0,06			0,4	2,27
1,5	0,77							0,5	3,30

a) length drawbar related to pivot point e-carrus b) position drawbar related to pivot point e-carrus c) position center of gravity to pivot point e-carrus d) position of trailerball in relation to pivot point car e) radius of ecarrus wheel

Table 3: Sensitivity analysis of geometrical design parameters – car + traffic-robot

Discussion: A pitching in the range of 1° seems to be practical for this first theoretical iteration. The length of the drawbar has a relevant impact to the pitching (table 3a). The application of simple physics, the longer the drawbar the smaller the forces and the smaller the pitching was expected. The long drawbar supports the comfort and the short drawbar is useful for a reduction in traffic space as explained in the introduction. The optimization of this conflicting goals is solved by a length adaptation of the drawbar with a spindle drive.

The mounting position of the drawbar (table 3b) has an impact to the effective lever of the traction torque, but the impact is small compared to the drawbar length. A height adaptation for comfort reasons is not necessary. However, it is open if for practical automation reasons a height adaptation is necessary for a reliable coupling to the different vehicles.

The design of the **e-carrus** vehicle has a big degree of freedom with regard to the position of the battery. With this positioning of the mass it is possible to influence inertia and the idle point of the pitching angle. Table 3c shows that this dimension has a notable impact on the pitching and so the vehicle comfort. The higher the centre of gravity the higher the inertia and the lower the pitching. This is a clear indication where to position the battery in the traffic-robot vehicle.

In established standards as the European Regulation 94/20 [18] the mounting position of the trailer-ball is defined for different vehicle sizes. However, the real position depends on the current loading of the car. As anticipated, the best situation is when the trailer-ball has the same level as the pivot point of the car. So traction forces do not produce an additional pitching torque. The table 3d shows that there is a relevant impact of the trailer-ball position for the comfort. Due to the fact, that it is not possible to influence this design parameter, only customers with a correct mounting position according the standards should be supported with the traffic robot.

Up to now the size of the **e-carrus** wheels is not finally defined. It should be a style parameter for a good design considering marketing aspects. However, the range from very small wheels to very large wheels (table 3e) shows a very strong impact to the pitching comfort. Large wheel size (diameter) is positive for the efficiency of the drive system, a small diameter is better for the comfort. As in most conflict of goals a medium size of the wheel will be chosen for best comfort and efficiency.

The presented sensitivity analysis shows the complexity of the system design. A very important finding of this first feasibility study is that it is possible to design the **e-carrus** system without any relevant impact to the pitching comfort of the car. In a next step a set of existing cars with a high market volume will be analysed to prove the market capability of universal usable design.

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