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NEW FOLDABLE URBAN CAR CONCEPT

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ABSTRACT

A growing demand for individual mobility, increasing number of cars and rising car dimensions require actions to improve the parking situation in urban areas. One way to scope with this challenge includes the implementation of new vehicle and transportation concepts, which focus on the substitution of conventional passenger cars. Alternative vehicle packaging and new chassis, propulsion and suspension technologies are capable to fulfill specific parking and important customer requirements at the same time.

In this paper, current urban car concepts with variable wheelbase technologies are investigated and a car concept including novel variable wheelbase mechanism and a new packaging solution for three passengers (EvoCare), is presented. The development of such vehicle and suspension concepts challenges common processes and requires multidisciplinary interaction of different disciplines, e.g. kinematics simulation, vehicle packaging, ergonomics & comfort, propulsion system layout, as well as driving dynamics and driving stability investigations. In this context, the novel suspension mechanism for the folding process is introduced and discussed. Furthermore, the required parking space and resulting costumer benefits of the concept are analyzed and illustrated by a comparison of different vehicle types in the target class.

1. INTRODUCTION

Parking space in urban areas is a scarce resource. In addition to aspects like urban densification and increasing numbers of vehicles, steadily rising vehicle dimensions lead to parking space shortages and complicated parking processes. This time, the vehicle fleet character is changing: besides small and compact cars, high volume Vans and Sport Utility Vehicles (SUV) are increasingly present [1]. The average length of passenger vehicles has grown by 4 % from 2000 to 2010, and the vehicle height has increased by 16.5 %. Supporting the big success of large car types, increasing safety requirements and legal provisions as well as comfort demands are responsible for those growing space requirements. Searching free parking lots is very exhausting. In a study of stressfully situations during car driving, more than 35 % of German car drivers define parking lot search as most stressful and driving pleasure reducing [2].

Small city cars are becoming increasingly popular, but customer benefits of these vehicle types are limited, because of small interior space and comparatively poor driving comfort. The three-seater urban car concept “EvoCare” from the Institute of Automotive Engineering, Graz University of Technology improves parking in urban areas without sacrificing the driving behaviour and costumer comfort (Figure 1). The vehicle wheelbase represents a significant variable for the external and internal dimensions of a vehicle, as well as for the driving behaviour on various road conditions. With variable wheelbase, the EvoCare concept combines both benefits, a short wheelbase for parking as well as increased wheelbase supporting driving stability at high velocities and under poor road conditions.

The conceptual development process of EvoCare is based on a comprehensive analysis of users' mobility and dynamic driving performance behaviour, including transport and driving distance demands of various user types. In case of those studies, several advantageous characteristics of three seater cars were identified. In a share of 44 % of all car-driving activities, the majority transport demand requires storage space for 4 pieces of goods and a maximum number of three seats. In this context, one challenge in the development process of the EvoCare concept was the fulfilment of sufficient space for 3 persons and 4 luggage pieces within a length of only 2.2 m in "parking mode" [3]. The variable wheelbase is realized by a specific folding system. During the folding operation from "driving mode" to "parking mode", the cabin is lifted, which decreases the vehicle length. The resulting low space demand allows small parking and maneuvering areas and provides the possibility of parking perpendicular to the road.

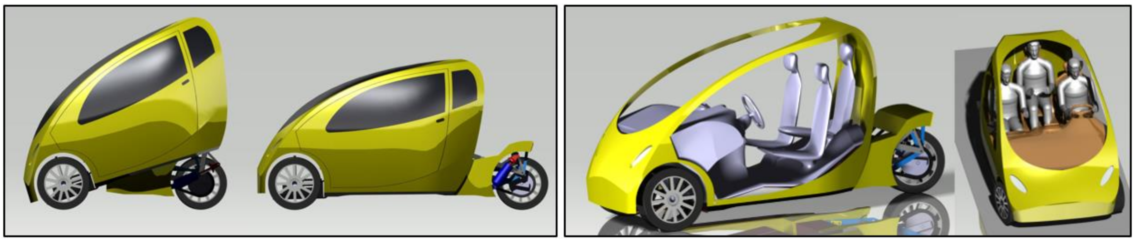

Figure 1: EvoCare. Left: Initial design proposal including folding mechanism. Right: 3D-model of the concept vehicle with passenger packaging solution [4].

1.1. Development targets

Initial research work included the definition of customer target groups, the elaboration of technical characteristics and the development of vehicle packaging and ergonomics concepts [5]. One aim of the subsequent concept development process included the realization of a suitable folding mechanism. Target of development was a simple, cost efficient and robust solution, which provides sufficient vehicle body stiffness and safety characteristics. To enable a low cost solution, it was a target to perform the folding process without additional actuators. This has required the development of a smart kinematics system, which is able to be actuated by the electric propulsion motor of the car.

1.2. Methology

In a first step, a technology and patent research of state of the art vehicles with variable body and wheelbase, focussing on chassis and variable suspensions technologies was carried out.
Wheel suspensions are safety relevant components; so the mechanical load situation had to been taken into account. Another important concern was the development of a cost-efficient solution for the variable wheelbase mechanism. Based on the vehicle-packaging concept of EvoCare, a new kinematic mechanism was created and tested in a comprehensive kinematics and kinetics simulation. The simulation was used for evaluation of research results, further optimization and the development of concept proposals. Furthermore, the space saving potentials of the novel urban car concept were discussed and investigated.

2. CONCEPT DEVELOPMENT

2.1. State of the art

Figure 2 demonstrates a selection of urban car concepts with variable wheelbases. State of the art are mechanisms, which are propelled by an actuator system, e.g. electric motors, hydraulic or pneumatic linear actuators. Kinematics and kinetics transmission is mainly performed with one link including a central bearing, or a linkage system. Such systems have an impact on stiffness and safety characteristics of the vehicles. For instance, a link with an integrated rear wheel and a central bearing has to carry high forces, leading to very stable and complex (heavy) constructions. With these solutions, sufficient ratios of vehicle length in driving and parking mode can be reached. However, complex wheel suspension systems, including wheel hub motors or even 360°-rotatable wheels, result in high costs.

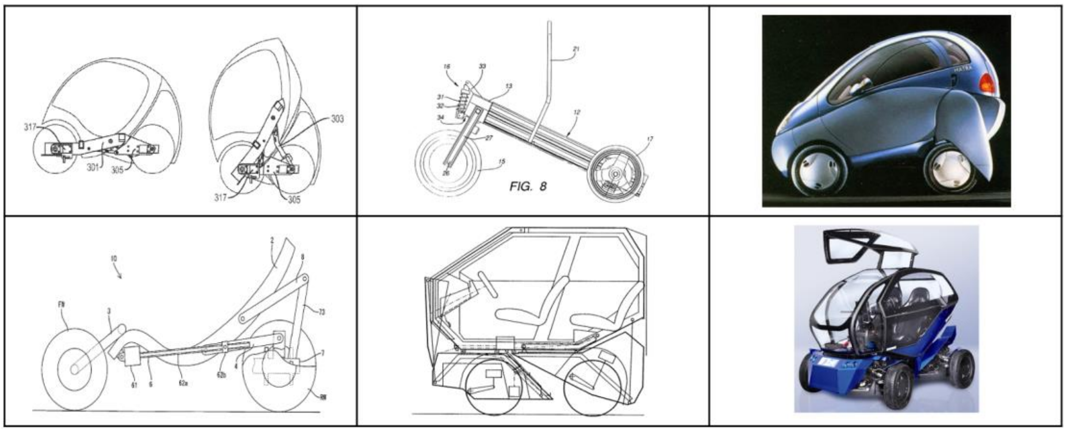

Figure 2: Selection of urban car concepts with variable wheelbase. Upper row: Hiriko folding mechanism [6], Ultralight Road Vehicle [7], Renault Zoom [8]. Lower row: Vehicle with adjustable wheelbase [9], car with small parking area demand [10], EO smart connecting car [11].

2.2 Concept proposal

Automobiles are usually carried, steered and driven by wheels. Number and layout of wheels as well as the type of propulsion and suspension systems have essential impact on the body concept, the interior and external dimensions, as well as on the driving behaviour. Figure 3 includes vehicle specifications and a kinematics model of a novel concept proposal for a variable wheelbase vehicle. The EvoCare concept was designed to fulfill the requirements on future urban cars, as described in Section 1.1. The simple vehicle architecture includes two main modules: A cabin containing passenger and luggage space as well as a steerable front axle, module (1), and the propulsion module including battery, inverter, electric motor and the driven rear axle (2). The mentioned folding mechanism is capable to move front- and rear axle relatively to each other. As a speciality, the folding process is significantly supported by a spring system (3) and the relative movement of cabin module (1) and propulsion module (2). In this way, the vehicle length can be reduced by one-third for parking and low-speed routing, without sacrificing driving comfort and safety at higher speed on highways trips.

Vehicle Specifications	
Vehicle mass (kg)	751
Lenght (mm)	3133
Lenght shortenend (mm)	2191
Width (mm)	1600
Height shortenend (mm)	2163
Performance (kW)	19,75
Max. speed (km/h)	100
Battery capacity (kWh)	12
Number of seats	3
Luggage space (l)	110

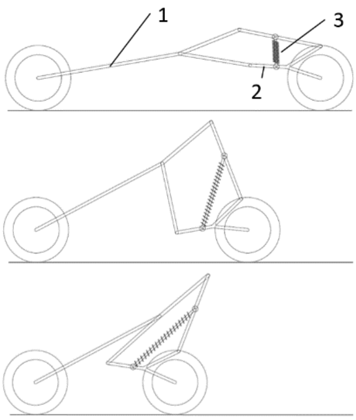

Figure 3: Left: EvoCare vehicle specifications [3]. Right: Novel kinematics proposal for vehicles with variable wheelbase.

Figure 4 shows folding mechanism and component positioning of the concept in the three operation modes “driving“, “folding“ and "parking“. The folding mechanism consists of the propulsion modul (2), linkages (3 and 4), main carrier (5), spring and damper (6), spots for fixation (7) and the corresponding fixation mechanism, which is integrated in the propulsion modul. In „driving mode“, the propulsion modul (2) is fixed connected with the cabin (1) by fixation spots (7). This enables a stiff body and a comfortable driving behaviour at high velocities, due to the long wheelbase. Both sides of the linkages (3 and 4) are mounted on the main carrier (5) and the propulsion modul (2). Via the linkages, the main carrier (2) with the integrated rear axle is moved towards the front axle.
For “folding” the released fixation device decouples the propulsion modul (2) from the cabin (1). The folding process starts by braking front wheels and subsequently driving the rear wheel by the main engine (9). Two springs and dampers (6) are rotateable mounted on the propulsion modul (2). The rear linkages (3), which are placed symetrically to the longitudinal axis of the vehicle, support the folding process until the parking position is reached. For “parking”, the fixation mechanism (7) connects the propulsion modul (2) with the cabin (1). The propulsion modul (2) houses heavy components like battery (8), electric traction motor (9), gear box (10), suspension with drive belt (12), rear wheel and fixation mechanism. A systematic positioning of the components leads to a deep centre of gravity that supports the folding process, due to a predefined movement of the heavy components during folding. Folding is solely operated and controlled by the traction motor - expensive actuators are not necessary. Vehicle dimensions and exemplary parking space demand of the “EvoCare” are shown in Figure 5 and Figure 6. The provision of a variable wheelbase enables a comparatively high variability of the vehicle length. In “parking mode”, the length is just 2.1 m, which technically enables parking perpendicular to the road and small parking and manoeuvring spaces in general. At a longitudinally parking lot with a length of 6 m length and a width of 2.3 m, 3 EvoCare vehicles can be parked side by side. The achieved space benefit is displayed in Figure 6 by a size-comparison with a Smart ForTwo and a BMW E63 Coupe.

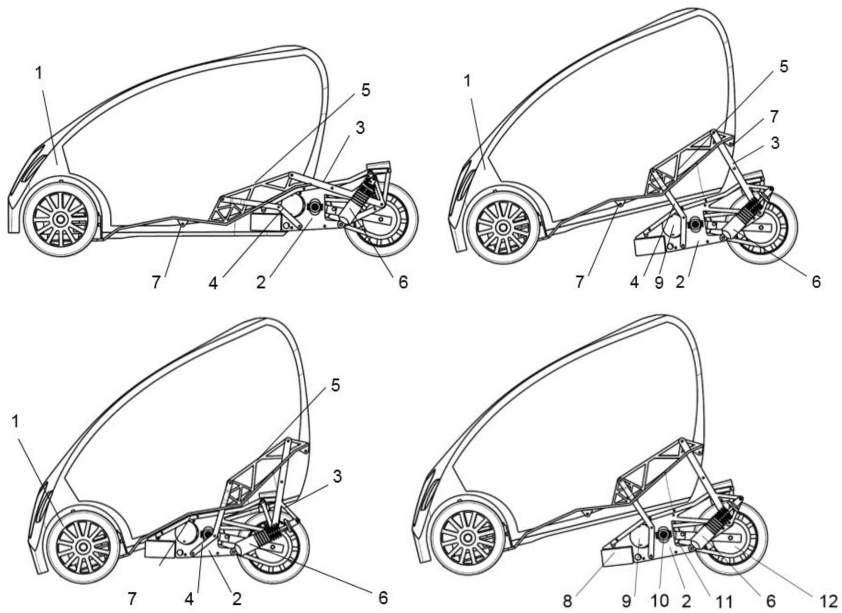

Figure 4: EvoCare driving modes and main (heavy) component packaging.

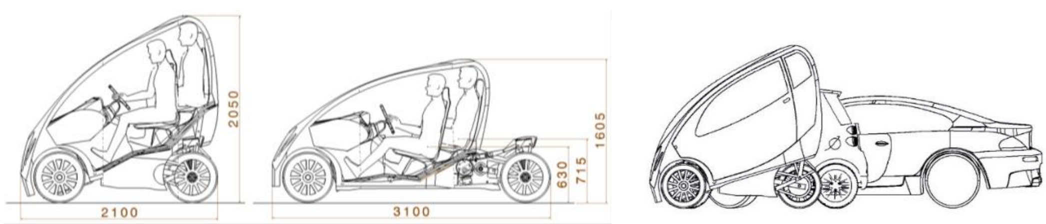

Figure 5: External dimensions (in mm) and size comparison with Smart ForTwo 2007 and BMW E63 Coupe 2010.

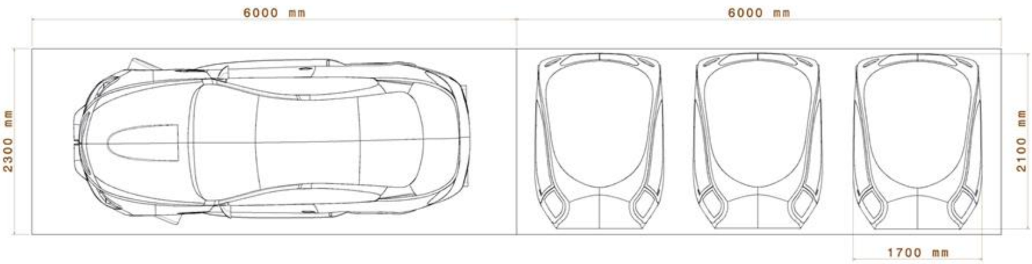

Figure 6: Exemplary EvoCare parking space demand.

3. KINEMATICS AND KINETICS SIMULATION AND TESTING

For realization of the new vehicle concept, the development of a suitable folding mechanism represented a main challenge. Target was the creation of a smart low cost mechanism, which was integrated into the vehicle architecture under consideration of vehicle packaging, ergonomics requirements and the electric propulsion system.
The folding mechanism was investigated by use of comprehensive kinematics and kinetics multi-body simulation. Besides geometrical and power-related aspects, friction behaviour between wheels and the road surface plays an important role for proper operation of the system. The coefficient of friction is defined by relationship of the wheel longitudinal force F_x and the wheel force normal to the surface F_y. Generally, the coefficients of friction μ and μ_{max} are defined as [12]:

$$\mu = \frac{F_x}{F_z},\ \mu_{max} = \frac{F_{x,max}}{F_z} \qquad (1), (2)$$

Road Conditions [13]	Bachmann [14]	Mundl [15]	Gustafsson [16]	Mitschke [17]	PC Crash [18]	Barace [19]
Asphalt, dry		1.05	1	0.88-1.15		
Concrete, dry	1.05 – 1.2	-	-		0.7 - 0.9	0.9 – 1.2
Cobblestone, dry		-	-	-		
Gravel, dry	-	0.5[a]	0.5	-	-	0.5
Asphalt, wet	0.73 – 0.81	0.85	0.7	0.7 – 0.95		0.7 – 0.9
Concrete, wet	0.66 – 0.8	-	-		0.5 – 0.7 (wet) 0.4 – 0.5 (very wet)	0.65 – 0.8
Asphalt, sandy	-	-	-	-	-	0.5[b]
Asphalt, snow	-	0.2	0.3		0.1 – 0.5	0.2 – 0.3
Asphalt, ice (scattered)	0.18 – 0.38[c]	-	-	0.07 – 0.02	0.05 – 0.25	0.1 – 0.2
Asphalt, ice	-	0.1	0.1			

[a] Mean value for loose gravel
[b] Assumed to be in the range of gravel
[c] Harsh ice

Table 1: Ranges of friction potentials of different road conditions, based on a literature review [19].

An overview of coefficients of friction potential of different road surfaces is shown in Table 1, which provided the basis for the folding mechanism characteristics simulation under different road surface conditions. Focus of the simulation was the determination of required folding forces and the needed coefficients of friction for rear and front wheels. Without enough “grip”, the rear wheels would spin and the front wheels would slip during the folding process. Because of this behaviour, the weight balance of front and rear axle is important. During folding, the centre of gravity moves and changes the axle loads, which requires a consideration of the loading situation in the simulation process. Furthermore, different load situations are caused by different car occupancy (1, 2 or 3 persons), which also changes the force situation and influences the kinetics characteristics during folding process. The multi body simulation provides longitudinal and vertical tire forces, under consideration of the rear wheel movement and the required coefficients of friction. In the simulation, the vehicle is divided into wireframe models: front carriage (cabin), rear carriage (propulsion module), linkages and wheels. The wireframes are linked with joints and represent the kinematic characteristics during folding. The tire forces are calculated by different occupancy situations from 1 to 3 persons (cabin: 340 kg, propulsion module: 350

kg, weight per person: 80 kg). The centres of gravity of the components are supplied by CAD-model data.

3.1 Simulation result

Figure 7 show the force curve of F_x at the rear wheel (longitudinal force at the 2 front wheels act equivalent contrariwise) and the vertical tire forces F_z for a folding length of 1100 mm without support of the springs ((6) in Figure 4). In "driving mode", the weight distribution of front and rear axle for all loading situations is between 43 to 57 % and increases to the rear direction during folding process. In parking position, the weight distribution is 36 % to 64 %. In this way, the (braked) front axle limits the maximum longitudinal forces. The simulation result for the coefficient of friction at the front wheels at launch of folding for one-person load is above a value of 1, and for 3 persons approximately 1.4, Figure 8. Under consideration of Table 1, folding will be possible for one person and restricted possible for 3 persons on dry asphalt surfaces. To solve this kinetics problem, additional springs have been applied (see Figure 3) to decrease the required longitudinal force significantly, Figure 8. The resulting coefficient of friction (Figure 9) suggests sufficient adhesion and a successful folding process by using these supporting springs under all possible conditions, even on wet road surface. With a maximum occupancy of 3 persons, the maximum required coefficient of friction is 0.46 at rear wheel and 0.57 at front wheels.

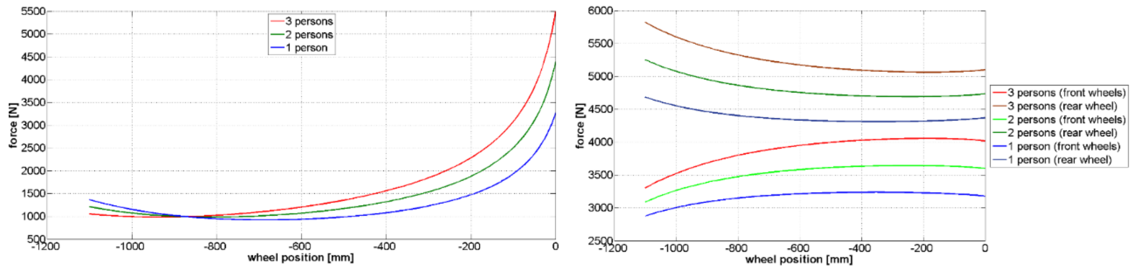

Figure 7: Left: Longitudinal force F_x for folding. Right: Normal forces F_z acting on the 2 front wheels and the 1 rear wheel.

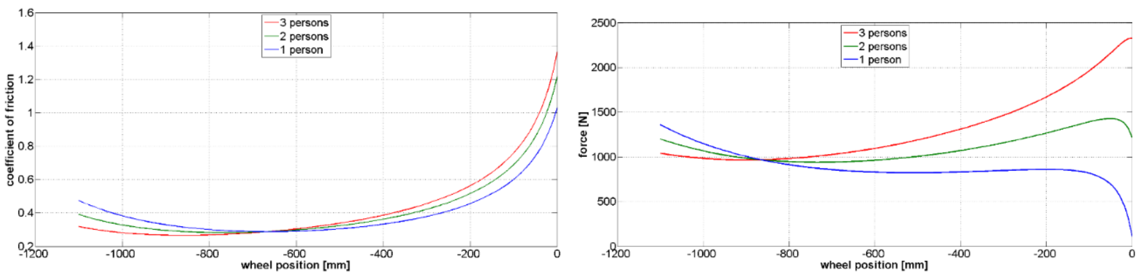

Figure 8: Left: Required minimum coefficient of friction at front wheels. Right: Reduced force F_x because of spring support in the kinematics mechanism.

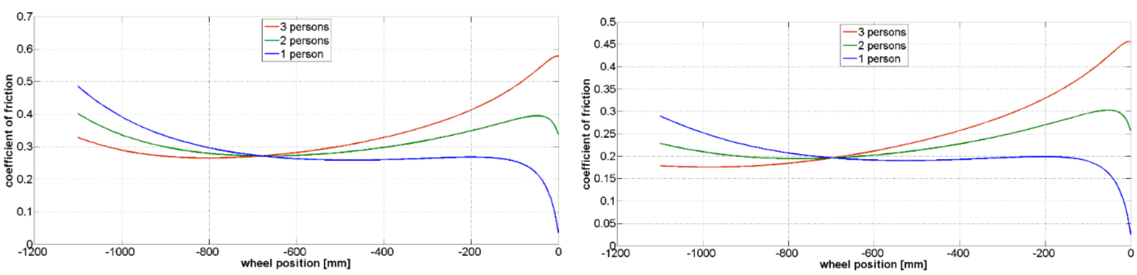

Figure 9: Required minimum coefficients of friction for successful folding. Left: Front wheels. Right: Rear wheel.

3.2 Prototype

For representation of the novel urban car concept and for verification of the simulation results, a vehicle model has been developed in scale 1:5 (Figure 10). Vehicle chassis, propulsion system and the folding mechanism with mechanical and electrical parts were built by low-cost components; many of them using radio-controlled model car elements. For comparable test conditions, model weight and axle load distribution under different loading situations have been considered. On dry and wet asphalt, the folding mechanism was successfully tested and confirmed the simulation results.

Figure 10: EvoCare Prototype in scale 1:5 including folding mechanism

4. CONCLUSION

Driving comfort, small parking spaces, low production costs, as well as satisfying different user requirements are essential for a successful implementation of future urban car concepts. Based on these challenging issues, a newly developed space- and cost-saving urban car concept has been presented. The novel concept integrates a new vehicle packaging design and an innovative folding mechanism for a variable wheelbase. As a difference to previous foldable car concepts, the presented folding mechanism does not need any additional propulsion system, like electric motors, hydraulic or pneumatic actuators. In this way, the EvoCare car represents a simple and economically producible approach. In combination with a smart packaging solution of all car components, the folding system is able to decrease the vehicle parking space demand by 33 %. In “parking mode” the length of the vehicle concept is only 2.1 meters, which allows parking perpendicular to the road and provides the basis for small parking and maneuvering spaces. Furthermore, the concept offers space for 3 passengers and luggage. It is based on a simple chassis design and smart packaging solutions of heavy electric drive train and energy storage system components. The folding mechanism is based on a newly developed kinematics, which has been investigated by use of computational kinematics and kinetics simulation and by a vehicle model. The simulation and model test results confirm a proper operation of the mechanism under different dry and wet road conditions. An optimization of the vehicle components weight distribution and the application of specific spring systems improve the longitudinal force situation during folding. In this way, the presented concept represents itself as a very cost-efficient solution to address one of the main challenges in urban traffic – the parking situation without sacrificing driving safety and comfort at higher speed operation.

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