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Innovative carsharing system: ESPRIT project

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Summary

ESPRIT project is a research project financed by Europe with 8.9 M€ funding in the framework of the program H2020 and coordinated by CEA (Commissariat à l'énergie atomique et aux énergies alternatives). The goal of ESPRIT project is to decrease the usage of individual cars in urban area and to complete the usage of public transport. It is small electric cars which can be mechanically coupled to create a road train. This vehicles can be available with car-sharing system in downtown and peri-urban area. The aptitude to be coupled in road train allows the distribution and insure the disponibility in station. That permits to propose a high reliabity system with a limited investment cost. This paper shows the work done and the results during the 3 years of the project.

Keywords: car-sharing; EV (electrical vehicle); light vehicle; mobility system; public transport.

1 Current car-sharing system

Inside big cities, the number of people which prefer to use public transport for quotidian trip and rent a car for exceptional trip is bigger each year. This kind of transport becomes usual inside city. Traditional public transport covers well the needs of urban people (less the night when public transportation is stopped). This phenomena can be easily link with the decrease of driving license passed by young people.

For peri-urban, it is again difficult because of the last kilometer between home and public transportation. One way car-sharing is the good solution to help people to suppress definitively their own car and use this kind of system. But, like all car-sharing system (cars or bikes) where the vehicle is taken in a station and returned in another station, there is always empty and full stations depending the hour of the day. Actually, people does the same way at the same hour to go to city center or to come back at home at the end of the day. Distribution of cars is of course harder than bikes. Two operators are needed to looking for one car. Or one operator which takes a public transport is needed to looking for one car. The use of big trucks to distribute vehicles is possible, but expensive and difficult in a downtown (and sometimes, it is forbidden).

The reliability and the profitable use of this kind of car-sharing system is linked to the good distribution of vehicles. A user which need a car to go to work, and which find an empty station, will never use again this system and will prefer another solution (its own car). Another issue for user is the difficulty to restitute vehicle near to the destination due to full stations. Due to these issues, the majority of car-sharing systems does not work at 100% of capability. Vehicles are really bad used compared to the maximum possibility. This phenomena is mainly due to the mistrust in the system for the user. That's why the **distribution is absolutely essential in a car-sharing system**.

The second main issue for the car-sharing systems is the initial investment cost for charge station infrastructure. It is a really important issue for a city or for a company to finance the installation of stations.

2 ESPRIT project

The goal of ESPRIT project (Easily distributed Personnal Rapid Transit) is to develop a light electrical vehicle (L7e-CP category) for urban car-sharing systems. The car-sharing system targeted by ESPRIT is the one way car-sharing (rent the vehicle in one station and return it in another station).

To solve all the difficulties mentioned above (distribution and cost), ESPRIT concept is a small and light electrical car able to be coupled with other ESPRIT vehicles (Fig. 1). This coupling allows to build a road train (8 vehicles maximum for the moment).

Figure 1: ESPRIT concept

The user takes one vehicle and use it like usual car. A trained operator can remove several vehicles from the station depending of the state of the distribution and drive the road train until the next empty station. Because of the size of the vehicle, it's possible for a user to distribute another car. Two cars coupled together as a similar length than usual family car.

2.1 Distribution

For distribution, an operator drives alone the road train and can distribute 8 vehicles in one trip. In the most efficient solution of existing usual concept, an operator uses a big truck which can contain 2 or 3 vehicles. So with ESPRIT concept, the distribution cost is divided by minimum factor of 3.

With equivalent budget, it is imaginable that the distribution will be more profitable for user and for the company which manage the system. And, as already mentioned, the best way to develop this kind of system is the improvement of the confident of the user inside the system. If system is efficient and if it is absolutely sure to find a vehicle in the station, it is then possible for user to suppress their own car.

2.2 Charge station

In station, ESPRIT concept stores vehicles in road train configuration (Fig. 2). Space of station is reduced due to the road train configuration. The space required by 8 vehicles in road train is equal to 4 cars parked one behind the others. So infrastructure investment is reduced significantly.

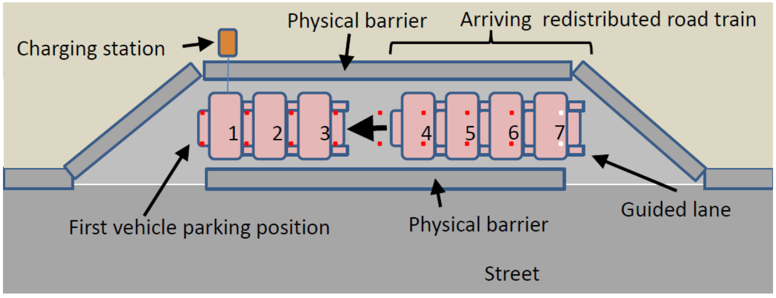

Figure 2: ESPRIT station

In station, ESPRIT is like FIFO (first in, first out) system. The first vehicle will be used in first and the vehicle is returned by the back. Operator can choose the number of vehicles to substitute from the station to complete another station.

In road train configuration, vehicles are electrically coupled. So a unique charger allows to charge the complete road train (8 vehicles maximum for the moment). Total cost for the charger of ESPRIT is 4 time less than the cost for 8 vehicles.

3 Technical innovations

3.1 Manoeuvrability of train

To be used in a town, the road train must be easy to drive. An operator must access easily to downtown with an 8 vehicles road train. To reach this goal, a pivot is integrated in the center of vehicle’s chassis (Fig. 3). For an alone car, the pivot is locked and front wheels can turn (like a normal car). In a road train configuration, only the pivot of the first vehicle is locked, but on follower vehicles of road train, pivots are free. That allows to obtain a monorail system really handy. All wheels of all vehicles takes the same way in a monorail mode (see Fig. 4).

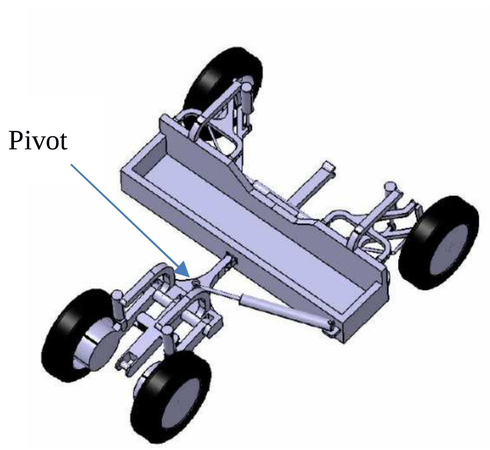

Figure 3: ESPRIT vehicle chassis

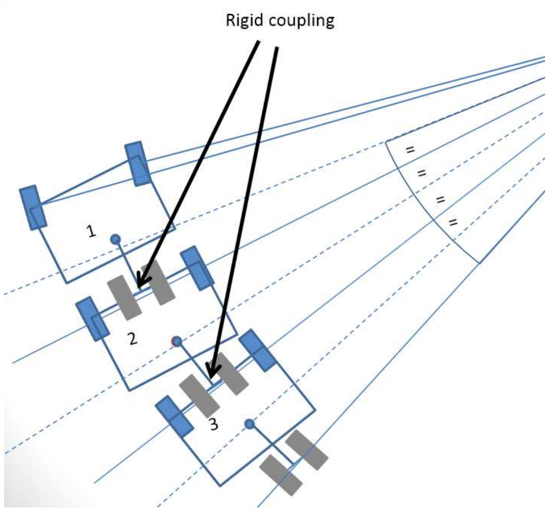

Figure 4: Monorail system

3.2 Choice of the components

The maximum number of vehicles in an ESPRIT road train during a distribution can be until 8. This train is particular because the first vehicle cannot tows alone the 8 vehicles. First, because it has not the power and secondly because, in this case, it tows vehicles with same mass of them. Apart from the prohibition due to regulations, an irreversible oscillatory phenomenon can appear when a vehicle tows a trailer with the same mass. The phenomenon is greatly amplified if there are several trailers. To solve these issues, all the vehicles participate to the propulsion of the train. Each vehicle power supplies their own electrical motors, so there is no vehicle “towed”. To do this, a communication between vehicles is necessary. First vehicle is the master and the followers become slaves and execute the orders given by the first vehicle. The first vehicle calculates in real time the oscillations of the road train with data provided from sensors placed in each vehicle. Algorisms determine the compensation needs and send orders to each vehicle independently.

To facilitate the oscillation compensation, ESPRIT vehicle is equipped with two motors. One on the back left and one on the back right. With a strategical command of torque on each motor, the oscillation can be controlled in real time. Another action can be apply on the front wheels. A little action on the steering system (2 or 3 degrees) may have a big impact on the oscillation compensation. The last action can be applied on brakes. An independent action on each brake of each wheel of the road train can compensate the oscillation.

The detail of algorisms used to do this compensation is already exposed and is the subject of other publication [1].

From hardware point of view, the necessity to control each steering system, each motor and each brake of each vehicle means to be equipped with electrical components driven by a communication bus. For motors, and steering, that is not a big problem to find electronical components with communication bus. But for brakes, it is more complicated. A conventional brake system is piloted mechanically with the pedal. A hydraulic assistance is applied and distributed on each wheel (ABS system). For ESPRIT project, a specific brake by wire was designed by Continental. This brake can received order from CAN bus (controller area network) and manages independently the pressure in the brake of the four wheels.

3.3 Communication bus

The communication between all vehicles in the road train were a real difficulty due to the road train specificity. Each vehicle must work correctly alone, but also in a road train configuration. And, in road train configuration, the position number of the vehicle is never known. The vehicle can be anywhere in the road train and the road train can contain 1 to 8 vehicles.

The CAN bus is the most used in vehicles because of its excellent reliability. So the most of electronic components in the car communicate with CAN. But to work correctly, this bus must be adapted. That means to connect a 120 Ω resistor at the both end of the network. In ESPRIT road train, it is impossible to know by advance where the beginning is and where is the end of the bus because road train are permanently reconfigured. The adaptation is not so easy.

It was decided to create 3 buses by vehicle. One bus communicates with components inside the vehicle. Another bus is dedicated to communicate with a potential front vehicle. If there is no front vehicle, the bus doesn’t work and wait a vehicle. And the last bus is dedicated for a potential rear vehicle. If there is no vehicle on the rear, the bus doesn’t work and wait a car. The three buses are linked with repeater (Fig. 5).

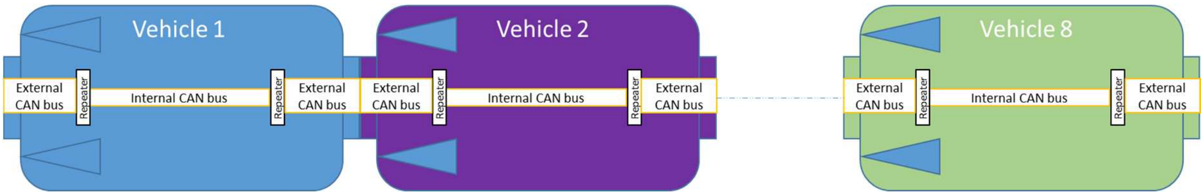

Figure 5: ESPRIT communication architecture

The oscillation compensation of the road train needs many messages between first vehicle and all components of the road train (motors, brakes, steering systems …). Furthermore, these messages must be send with a very high frequency, to balance in real time the oscillations. The road train must go up 45 km/h without any oscillation. For that, some messages are transmitted every 10 ms. Time lost between the first and the last vehicle must be negligible to avoid a saturation on the bus. To transmit messages through all vehicles with the minimum loose of time, quick repeaters are used. Each repeater loses some nanoseconds only.

But despite the use of these very fast repeaters, it was necessary to decrease the speed of the communication until 250 kB/s (we hoped 500 kB/s initially). The consequence of this reduction of speed is the overcharge of the bus at 70 % of load. It is really important for a can bus.

In conclusion, for a future development of this kind of vehicle, CAN bus will certainly be replaced by a higher speed communication bus.

3.4 Battery voltage

ESPRIT vehicle is considered like a L category. That means heavy quadricyle vehicle. Regulation specify a maximum mass of 450 kg for the complete vehicle (without battery). The global mass of the vehicle is already impacted by mechanical specificity, by additional coupling device and by additional electronic components and sensors to manage the road train.

To reduce the mass of the traction chain, it was decided at the beginning of the project to use “high voltage battery” at 400 V. This is an innovation because in this kind of vehicle, the low voltage is the most widespread. Manufacturers prefer low voltage because of the safety aspect. In ESPRIT project a complete and a global safety analysis was done in order to avoid any risk for the user. The use of high voltage allows to reduce the mass of converter which transform DC voltage of the battery into AC voltage for motors. The mass of the both Sevcon converters is 7.4 kg for a total of 9 kW in the output. And the mass of the both Parkers motors is 26 kg for a total power of 10 kW. To give a comparison, for low voltage converter, the mass is similar for the main components but with additional cooling system.

3.5 Capacity of the battery

The capacity of the battery is chosen to do a trip length of 30 km. This value is chosen with a big margin. The mean trip for peri-urban usage is only 4 km at 35 km/h. And the mean trip for urban usage is 3 km at 25 km/h.

That has a big impact on charge time. Each charge will be only micro charge and it should take only 2 or 3 minutes. In charge station, the charger is able to charge the 8 vehicles thanks to the electrical link between vehicles. Thanks to the little energy of charge needed on each vehicle, the charger can be a standard charger (7 kW) and it is not necessary to choose a charger 8 times more powerful.

In usual system, one 7 kW charging station is able to power supply two vehicles (one charging station usually supports two charge plugs). In ESPRIT concept, the 7 kW charging station is able to charge up to 8 vehicles.

So the cost is divided by 4. Or, with an equivalent budget, there is the possibility to build 4 times more stations.

The strategy is to charge the vehicles one by one, starting by the first (because, it will be the first to leave the station).

3.6 Exchange energy strategy

The capability to exchange energy between vehicles is a really big advantage in charge station as mentioned above. Another advantage is the possibility to exchange energy during a road train trip. The 10 or 15 minutes duration of the trip to drive the road train from a full station to an empty station lets the possibility to balance energy between vehicles with more energy to the first vehicle which will be the next vehicle used by a user.

This exchange of energy between vehicles allows the possibility to build some stations without charger. Depending on the geographical location of the station, it can be interesting to build an intermediate low cost station without charger. The exchange of energy between cars makes it possible to always maintain a sufficient level of charge on the first vehicle.

The exchange energy between vehicles can be managed by a global fleet management system.

4 Project chronology

Seeing the number of mechanicals and electricals parts to control this vehicle, the development was done in several steps and is done on 6 vehicles.

The **first** prototype contained the strict necessary elements to move the vehicle: battery pack, motors, inverters, charger, DC/DC converter, intelligent unit who manage the security and start auxiliaries, intelligent unit which manage motors, screen, “Drive Neutral Rear” buttons and a datalogger to monitor the communication bus. This first vehicle is constituted with a steel chassis (easy to realise) and had for principle to check and validate the concept and propulsion chain. This vehicle was gone in Germany to developed, check and validate the special brakes. This first vehicle was very important for project. The other vehicles were adaptation and improvements from this first one.

Figure 6: First prototype

A **second** prototype was done on the base of the first one with adaptations of mechanical parts. The assisted direction piloted by the intelligent unit which controls motors was added and tested. Then this vehicle was sent in Germany to include the automatic guiding system which helps the user to be aligned during coupling. Some mechanical modifications were done on central pivot.

A **third** prototype allows to develop the coupling device. Tests of traction was done in road train with prototype number 1 (updated to be setting in road train). Communication inter vehicle was also coded and validated.

Figure 7: Prototypes 1 and 3 in road train

The **fourth** prototypes allows to do a technological gap because chassis becomes in aluminium to replace the steel and win mass. A road train was done with prototypes 1, 3 and 4. This road train does tests of road holding and brake on a racetrack.

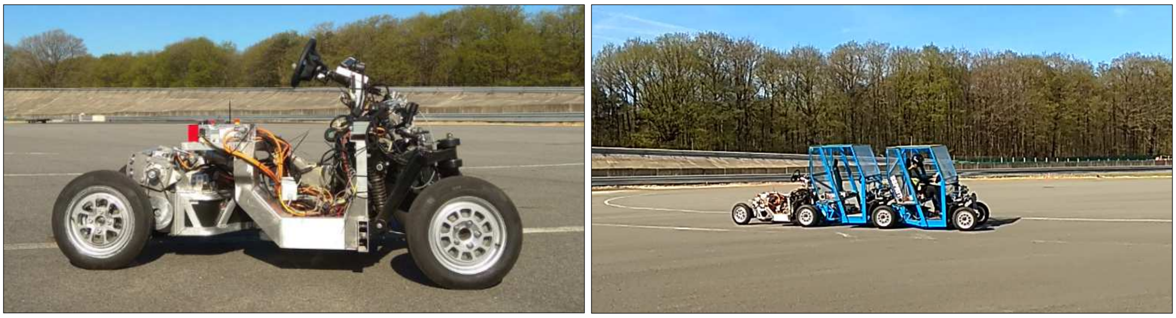

Figure 8: Prototype 4 and prototype 4 in road train with 1 and 3

Prototype number 5 allows the development of auto body and corrects some electrical and software bugs. Other equipments like lights, klaxon, wiper are integrated and validated. For all of these equipment the communication between vehicles in road train is necessary. For example, only the first vehicle can powered the full light. But all the vehicles must power the turn lights at same time.

To finish, **prototype number 6** was delivered in last June. It integrates all the functionalities developed until now.

Prototypes 5 and 4 were updated to integrate all the functionalities and allows to do a complete finish road train with 3 vehicles.

Figure 9: prototypes 4, 5 and 6 in road train [2]

5 Demonstration and conclusion

Since last august, several demonstrations are done in several cities: Lyon, Glasgow and Hospitalet de Llobregat.

Many medias cover these events (Euronews, BBC news, Le progrès, France 3, Lyon première, The Herald, La tribune, Intelligent transport or Bref Eco …)

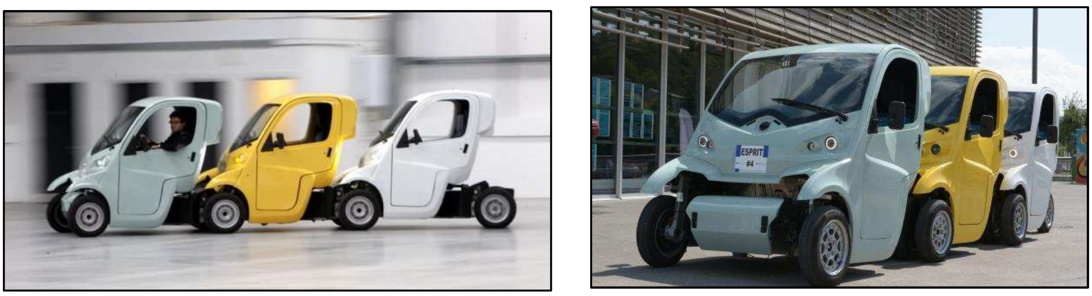

Figure 10: Photography come from media [3] [4] [5] [6]

To conclude, this project shows that ESPRIT concept is technically possible. Some improvement should be done to industrialise the vehicle with the better final cost but the concept is validated and is a good innovation for future car-sharing developments.

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20 patents active.