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"Gheorghe Asachi" Technical University of Iasi, Romania

EXPRESS-CAR-HIRE – A NEW CONCEPT FOR ELECTRIC VEHICLE HIRING WITHIN AIRPORT TERMINALS

Laszlo Bartha[1], Mircea Fulea[2*], Bogdan Mocan[2]

[1]*Technical University of Cluj-Napoca, 28 Memorandumului Str, 400114 Cluj-Napoca, Romania*
[2]*Research Centre for Engineering and Management of Innovation, Technical University of Cluj-Napoca, 28 Memorandumului Str, 400114 Cluj-Napoca, Romania*

Abstract

While trying to reduce the air pollution caused by traditional traffic means like planes and conventional cars, new concepts of car sharing (either conventional or electric) emerged. Although many such concepts are daring and innovative, they're not implemented on a large enough scale; to help reducing air pollution, the acceptance (and hence implementation) of these concepts needs to systematically increase. This paper introduces a design methodology for such a *concept* - based on competitive engineering tools - which, besides considering environment protection requirements, aims to determine *a better acceptance of the concept* and to be an effective starting point for developing a business plan, a feasibility study, for starting a joint venture etc. This is envisaged through identifying the added value incorporated by each functionality and component of the concept; afterwards, when implementing it, adequate effort can be directed towards the distinctive features it will provide. The methodology is then applied to build an environment-friendly transport concept - *EXPRESS-CAR-HIRE* - which is designed to suit airport terminals, which have particular constraints regarding space and efficiency.

Key words: car sharing concept, competitive design, electric vehicles

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1. Introduction

The last decades brought a significant increase of the world's population (United Nations, 2013), which in turn brought a significant demand for transportation services. Nowadays, flights are the first option for long distance travelling. Planes usually connect important urban centres, and airports are located quite far from the actual points of interest. As a consequence, car rental facilities within airports became a natural expectancy of air travellers.

Car rental within airports seems to have started even before the Second World War. The first company to provide such services was noted to be Hertz, in 1932, within the Midway airport of Chicago (Hertz, 2013). In 1946, Avis (within the Willow Run airport in Detroit) was noted to be among the first companies to report airport car rental as their main focus (starting with a fleet of three cars) (Avis, 2013). Nowadays it's extremely difficult to find an airport without at least one car rental company. Moreover, when comparing figures of on-airport and off-airport revenue for car rental markets, it's easy to conclude that, at least for western countries, most cars are being hired from airports (AM Mindpower Solutions, 2011).

Both planes and cars are important sources of air pollution, as a lot of carbon calculators (many of them available online, such as (***-1, 2013)) indicate. Moreover, jet planes are noted to have a climate impact nearly three times greater than that of the carbon dioxide produced by burning their fuel (***-2, 2013), (***-3, 2013). Car pollution might also be underestimated, as it is difficult to assess the additional environmental costs of producing and

* Author to whom all correspondence should be addressed: e-mail: mircea.fulea@staff.utcluj.ro; Phone: +40745022807

distributing the fuel. As air travelling and airport car rental usage figures are very likely to increase, it's easy to infer that the corresponding environmental costs (namely air pollution) will increase as well.

Solutions to reduce air pollution caused by planes are highly challenging, mostly because changing travelling habits of people is a difficult and slow process. This paper addresses the other component of the environmental issue mentioned above, by providing a novel and attractive (eco-friendly) alternative to the traditional car rental concept. The proposed alternative aims also to become an *eco trend-setter*, mostly due to its eye-candy, to raise the environmental awareness of people who mostly use environment-unfriendly travelling means such as planes and traditional cars. Of course many appealing alternatives already exist (as a simple web search easily reveals), but many of them seem to be rather artistic approaches. However, the authors of this paper consider that, apart from providing eye-candy (which is indeed mandatory), such alternatives should serve as a ground for further analysis and development, for instance through an entrepreneurial plan, feasibility study, grant proposal, because they should eventually be implemented. Obviously, a thorough technical insight, cost-benefit analysis data or time estimations cannot be addressed within a concept proposal, but commercial success should be definitely envisaged. The competitiveness (commercial success) of the proposed concept is therefore addressed, through an adequate design methodology.

Literature reviews show that, apart from the new hybrid and electric cars on the market, a couple of alternative concepts to the classic car rental have already been developed and a few have been even implemented. However, most of them are specific to urban centers, and “porting” them to airports, where specific constraints (like car storing space, specific regulations, possible overcrowding) do exist, is quite challenging.

Moreover, as noted by (Santos et al., 2010), sustainable land-use policies will probably direct urban development towards a form that allows public transport, walking and cycling to be at the core of urban mobility. Therefore, future car (vehicle) sharing concepts will be designed to be consistent with such policies; hence the need for a novel airport-specific vehicle-sharing concept.

2. The problem

As it can be easily seen today, airline traffic and car hiring services are strongly tied together. Currently, the hiring process is done in two ways: online or directly at a specific office. Either way, the process consists of three important steps: (a) choosing the pick-up and return locations, (b) choosing the vehicle type, according to the customer needs and desires, and (c) filling the required forms. So, from a user's perspective, the process seems to be easy and straightforward.

To provide such services, a provider needs (a) adequate space (usually large), (b) trained personnel, (c) numerous and quite complicated procedures. Moreover, the vehicles used (although there are some rare exceptions) use traditional fuels, thus contributing to air pollution.

However, nowadays trends are opposite: due to overpopulation, innovative solutions are sought to cope with reduced spaces, and means of polluting less (or at all) are evaluated (and even implemented in an incipient phase). To shorten process times (thus getting cost reductions and happier customers), automation and ITC technologies are also part of these trends.

To address these challenges and trends, an adequate starting point is the car sharing concept (***-4, 2013), (Wikipedia, 2013), which is a less car intensive means of urban transport. Apart from the environmental aspects, car sharing is beneficial also for the end users. A saturation of car ownership has been noticed over time (The Economist, 2013), and - according to the same literature source - car sharing can reduce car ownership at an estimated rate of one rental car replacing 15 owned vehicles.

Some new approaches on providing car sharing services do exist. For instance, the car2go concept in Ulm, Germany (Firnkorn and Müller, 2011), was built around a free-floating car-sharing system. It allows its users to take and leave vehicles at any point within the city limits; there are no fixed stations and one-way trips are possible without a booking requirement. While having an important potential of reducing carbon footprints, the concept is linked to urban centres and it's probably not suited to replace car hiring within airports.

The Autolib concept implemented in Paris (Autolib, 2013) is a short-term car sharing system, available 24 hours, 7 days a week, based on more than 250 central stations in the Ile-de-France region (and aiming over 1000 stations in the near future). Cars are completely electric, can be returned to any station, are self-serviced, and should be an alternative to the personal car. Booking and usage are automated, based on the customer's ID and credit cards. As with the previous example, it is not (yet) aimed towards replacing car hiring within airports.

Two other innovative car sharing concepts are also worth to be added to the above list: Flightcar (Smith, 2013) and Zipcar (Zipcar, 2013), both with a growing customer range, but they still rely on traditional cars (although their fleets include mainly fuel-efficient vehicles).

To sum up, car sharing seems to fit well to the environmental and customer needs. However, to be successful, such a service needs to be also competitive (Brad et al., 2010). Many car sharing concept implementations, including those reviewed above, did benefit of public support and probably of adequate (including public) funding. However, for this concept to become wide-spread, (economic) competitiveness should also be (systematically) addressed. While reviewing the specific literature (both scientific databases and the world-wide-web), *such a straightforward methodology or approach could not be identified*. The aim of this paper is to introduce such a methodology, based on competitive engineering tools like QFD and TRIZ, that actually *plans* the competitiveness of an environment-friendly car-sharing concept implementation, focusing on environment, costs, technical solution, and also on *customer experience* (rather than simply on customer satisfaction) (Teixeira et al., 2012).

It may be difficult (if not impossible) for any methodology or approach to "build" a certain competitiveness level into a car-sharing system. However, competitiveness should be more than "it should have eye-candy" or "it should use cutting-edge technologies". Considering the life cycle of such a system (e.g. from *core idea* to *vision, concept analysis and development, blueprint, refinements, actual implementation* and up to *exploitation* and *withdrawal*), competitiveness planning while developing the concept will serve as a support (under the form of extremely relevant knowledge) for the *refinement* and *actual implementation* phases, which will eventually determine the "final" competitiveness level. In other words, addressing competitiveness in an early stage in the life cycle (i.e. concept development) is considered to be critical for the overall commercial success.

3. The methodology

To address the challenges identified in the previous sections, the authors of this paper propose a design methodology for a car sharing / hiring *concept*; the methodology is then applied to develop a car hiring concept for airports, starting from the following specific (market) needs: *restricted space*, *increased security*, *efficiency*, *effectiveness*, *reduced costs*, *environmental impact*, and - the most important one - *customer experience*. The starting idea is a generic car-sharing concept, which is further adapted - using competitive engineering tools - to be effectively used in particular locations such as airports. The market needs above were identified by conducting a survey over the internet and using the findings of a related internal project performed by one of the authors. The resulting concept - named *EXPRESS CAR HIRE* – will be presented within the next section.

For clarity, the methodology proposed in this paper aims to structure the *concept analysis and design* phases of a car-sharing system's life cycle (as described in the section above). It does not address the implementation phases, although it supports them through relevant information determined while applying it. The core idea behind the methodology is that each element of the concept (functionality or physical component) should incorporate adequate added value (in terms of both technical performance and customer satisfaction) to the overall concept. The added value should be proportional to the costs of the specific component (and/or effort for developing it), or - in other words - money should be invested in a component or functionality proportional to the added value it incorporates. The methodology blocks are presented in Fig. 1. Within the first block - "understand" - the vision is stated, the stakeholders are identified, and the market needs and performance characteristics are formulated.

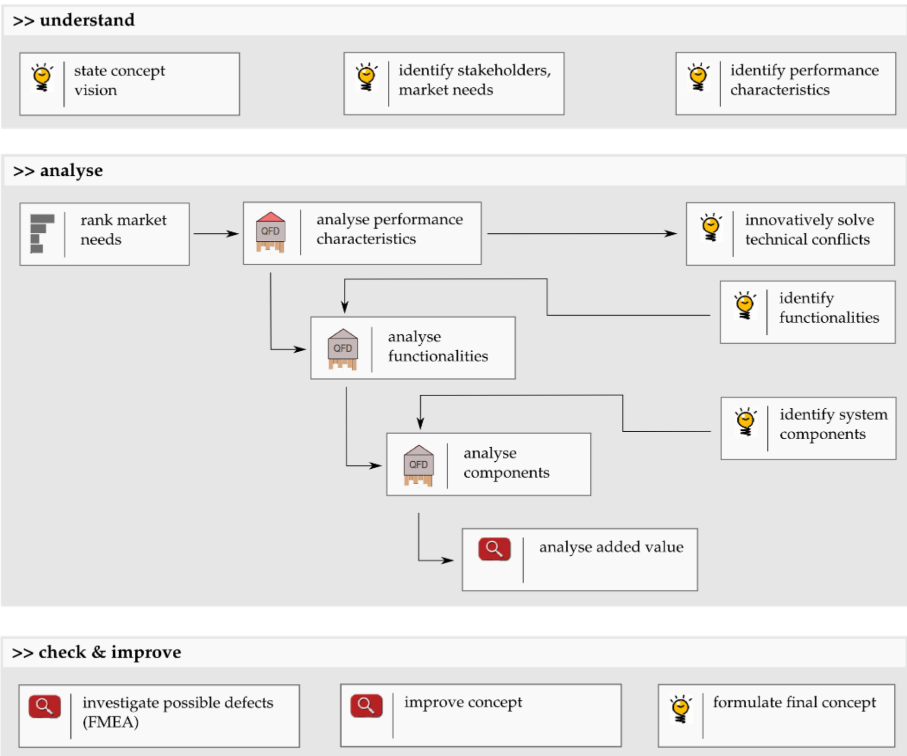

Fig. 1. The proposed methodology

The second block - “analyze” - consists of the following steps:

- rank market needs; use a systematic tool like the AHP method (Brad, 2004) to get the importance level; calculate the consistency index
- set metrics and optimization trends for each performance characteristic; determine the performance characteristic weights, using the QFD method (Brad, 2004) (deploy them against the market needs)
- identify all possible technical conflicts between performance characteristics (in the House of Quality roof) and use an innovative problem solving tool like the TRIZ method (Brad, 2004) to solve them without compromises
- identify the function list of the new system (basic, auxiliary, harmful functions) and determine their weight by applying the QFD method (deploy them against the performance characteristics)
- identify the components (modules and interfaces) of the new system and determine their weight by applying the QFD method (deploy them against the functions); the weight represents the *added value* (both from a customer and quality / technical perspective) that a component brings to the overall system
- analyse added value: estimate the cost for developing / acquiring each component and compare it to its weight (added value); ideally, estimated cost and added value should be proportional

The third block - “check and improve” - consists of three steps:

- estimate possible failures and take measures to avoid them; the FMEA or AFD methods (Brad, 2004) can be used in this step
- for the components for which estimated cost and added value are not proportional, try to reduce the gap by applying innovative solutions; the TRIZ method can be used in this respect
- based on the findings of the above two steps, formulate the final concept idea

The final concept idea (the result of the methodology) can be further used for developing a business plan, a feasibility study (and a cost-benefit analysis), for starting a joint venture, etc. Its key advantage is that it already offers an insight on topics like technical performance level, key functionalities and components and added value, therefore adequate resources (effort, budget) can be invested in implementing functionalities and/or meeting performance characteristics (corresponding to the “incorporated” added value of each functionality or importance of each performance characteristic).

4. The *EXPRESS CAR HIRE* system

This section summarizes the results obtained using the above methodology for developing a new airport car hiring/sharing concept that addresses the challenges highlighted in the first two sections of this paper.

Step 1.1 consists of formulating the concept vision: “The proposed system aims to complete (and eventually replace) the existing car hiring systems in airports, for better space use, for a completely automated car hiring process, for hiring time reduction, and for replacing the actual vehicles with a unique, electric, environment-friendly model. The functionalities provided to the customers should be challenging and enhancing the overall user experience, even becoming a trendsetter in vehicle usage behaviour“. The concept vision may look ambitious; however, implementation is not foreseen in the near future – the concept should rather serve as an effective base for a larger project proposal.

Within step 1.2 the stakeholders and market needs were identified. For the *EXPRESS CAR HIRE* system, the stakeholders are its customers and the operating company (e.g. the airport hosting it). The market needs list is: (1) increased automation, (2) ease of use, (3) increased vehicle number, (4) increased vehicle autonomy, (5) environment-friendly vehicles, (6) pleasant design, (7) compact vehicles, (8) comfortable vehicles, (9) reduced cost, (10) assurance, (11) reduced energy consumption, (12) reduced space requirements, (13) minimal maintenance, and (14) conformity to standards and regulations. These market needs reflect the requirements of all the identified stakeholders. Regarding need (9) reduced cost, this is seen as both the cost for the end user and the cost for the entity that implements the concept (e.g. cost of the storage system plus cost of the vehicles minus subsidies that might apply, as discussed in (Georgakellos, 2011)).

Within step 1.3 the performance characteristics were determined in order to adequately respond to the previously identified market needs. The performance characteristics list is presented in Table 1.

For performance characteristic 12, the measuring unit is „customer productivity“, which may be evaluated through interviews and surveys. For performance characteristic 13, the measuring unit is “percent of functions that complete without errors”. For performance characteristic 15, the measuring unit is “customer satisfaction on vehicle comfort”, which may be evaluated through interviews and surveys. For performance characteristic 16, the measuring unit is “customer perception on vehicle performance”, which may also be evaluated through interviews and surveys.

Within step 2.1 the market needs were ranked using the AHP method; the results are shown in Fig. 2. A consistency ratio was also calculated according to the AHP methodology: CR = 0.031 (< 0.1, therefore the analysis is consistent). According to the AHP results, the most important requirements are related to the automation level, environment, and space that the system occupies. The technical solution adopted by *EXPRESS-CAR-HIRE* will therefore especially focus on these three requirements.

Table 1. The performance characteristics of the *EXPRESS-CAR-HIRE* system

No.	*Performance Characteristic*	*Measurement*	*Optimization*
1	number of vehicles	-	⇥
2	storage space size	m^3	↓
3	photovoltaic panel size	m^2	↓
4	vehicle size	mm	⇥
5	power consumption	kWh	↓
6	noise level	dB	↓
7	vehicle pick-up time	min	↓
8	vehicle return time	min	↓
9	vehicle processing time (by the system)	min	↓
10	system installation cost	EUR	↓
11	operating and maintenance cost	EUR	↓
12*	usability	-	↑
13*	reliability	%	↑
14	(high) availability	%	↑
15*	vehicle comfort	-	↑
16	vehicle perceived performance	-	↑

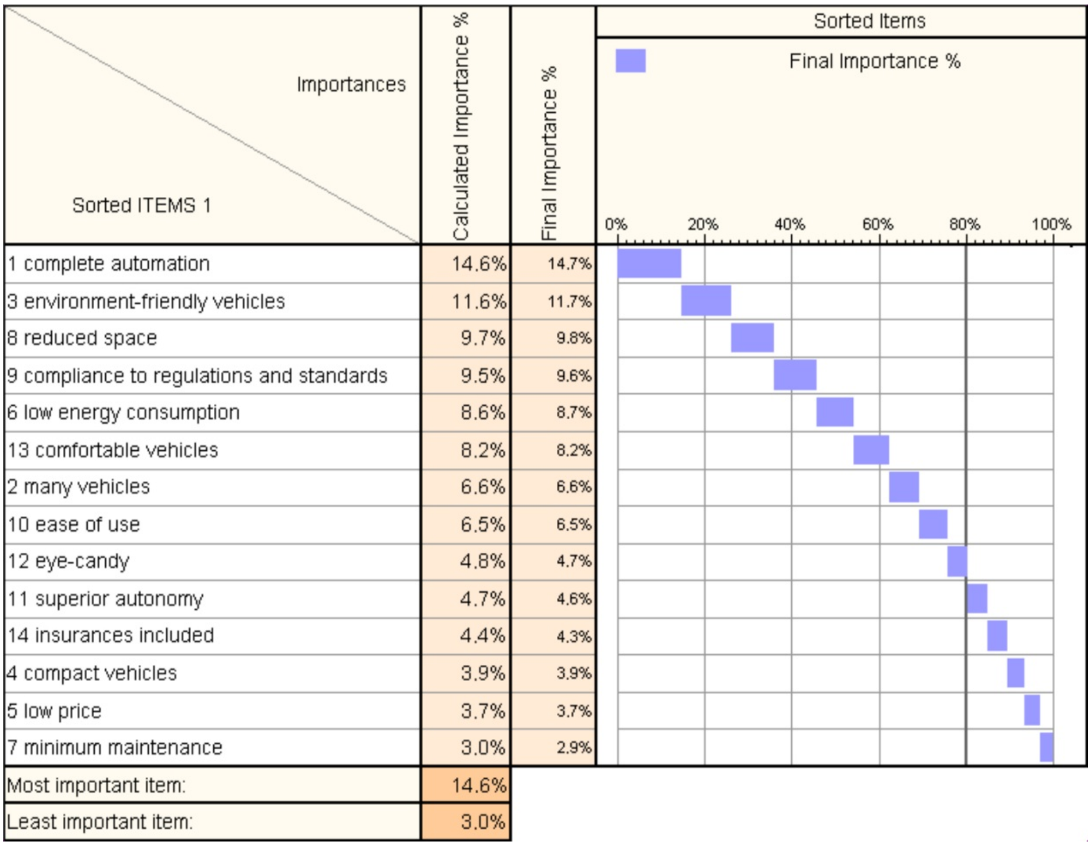

Fig. 2. Market needs ranking using the AHP template of the Qualica QFD software tool

During step 2.2 the performance characteristics were assessed using the QFD method; the results are shown in Fig. 3.

According to the results, the most important performance criteria are (2) storage space size, and (9) vehicle processing time.

During step 2.3 the significant technical conflicts between performance characteristics were identified: (1) number of vehicles vs. (2) storage space size, (1) number of vehicles vs. (5) energy consumption, (4) vehicle size vs. (15) vehicle comfort, (1) number of vehicles vs. (9) vehicle processing time, and (4) vehicle size vs. (9) vehicle processing time. After addressing them using the TRIZ Contradition Matrix tool, the following relevant innovative principles were taken into account: (5) *Merging*, (10) *Preliminary action*, (15) *Dynamics*, (1) *Segmentation* and (7) *Nested doll*. Based on those, the following guidelines were issued:

- simultaneous operations: when a platform storing a vehicle is lowered, the other platforms (storing vehicles) on the same level are indexed one position, and the freed platform will be positioned in stand-by
- after each vehicle pick-up or return, the platforms - both free and loaded - are being re-

arranged in such a way for a future pick-up to be performed in a minimum time;

- reservations possible over internet, for returning customers, thus minimizing time spent with the actual pick-up process (each customer can get a magnetic card with the adequate identification data)
- build a completely modular system, to allow setup in any airport location;
- to minimize occupied space, the transfer of empty platforms from the pick-up to the return spot can be made at an underground level; for small spaces, even the pick-up and return spots could be placed as "ground zero".

The guidelines determined in this step will be used in the technical phases of the concept design process (e.g. for blueprinting functionalities and components).

During step 2.4 the system functionalities were determined and then analysed in relation to the performance characteristics. An adapted version of the functional perspective design methodology from (Fulea and Brad, 2011) was used to determine the functionality list (1 - *vehicle manipulation functionality sub-set*, 2 - *user (customer / maintainer / service) interface functionality sub-set*, 3 - *energetic system functionality sub-set*, 4 - *(electric) vehicle functionality sub-set*, 5 - *vehicle storage system functionality sub-set*).

Fig. 4 shows the House of Quality used for the analysis.

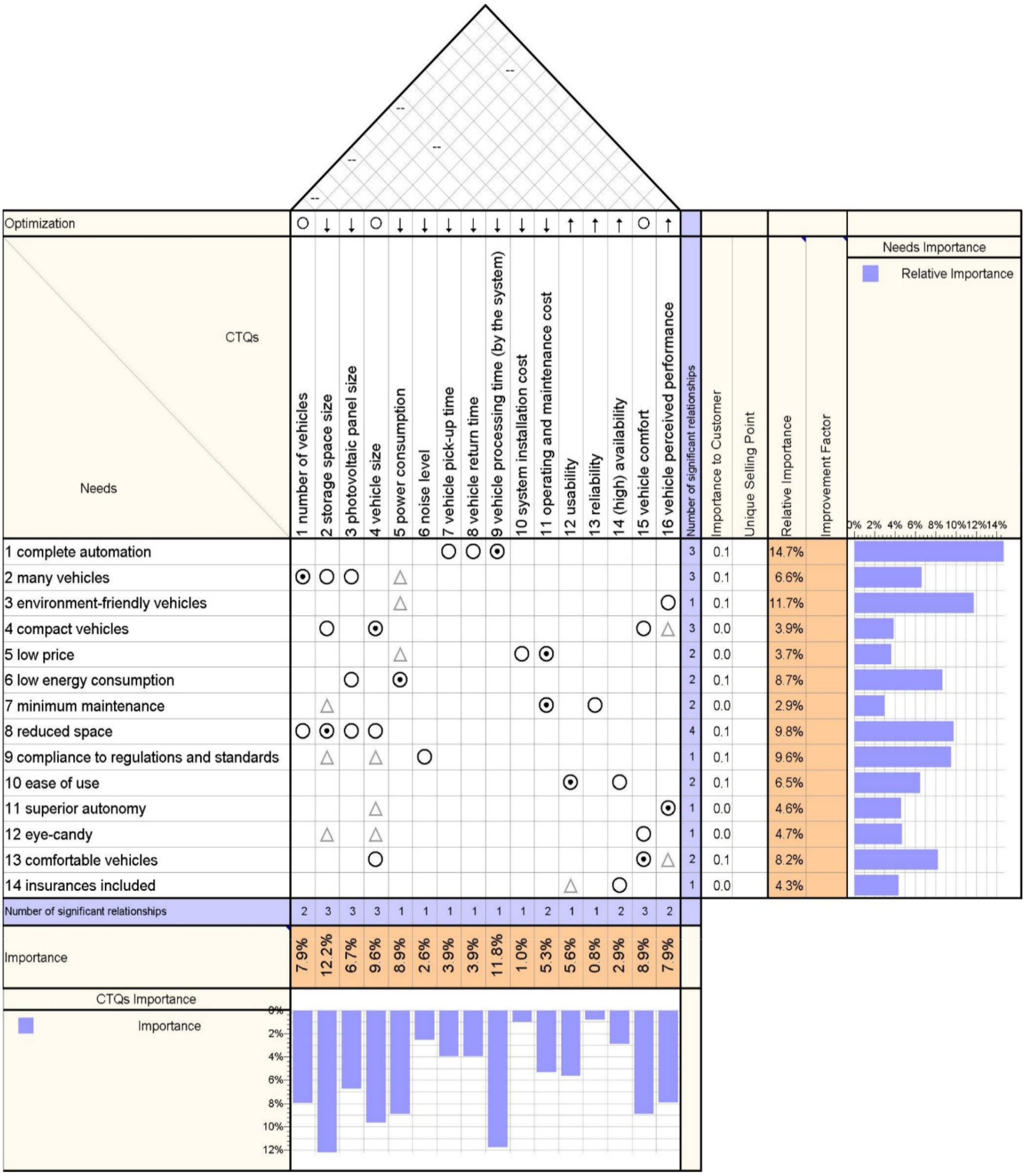

Fig. 3. Performance characteristic analysis using the House of Quality template of the Qualica QFD software tool

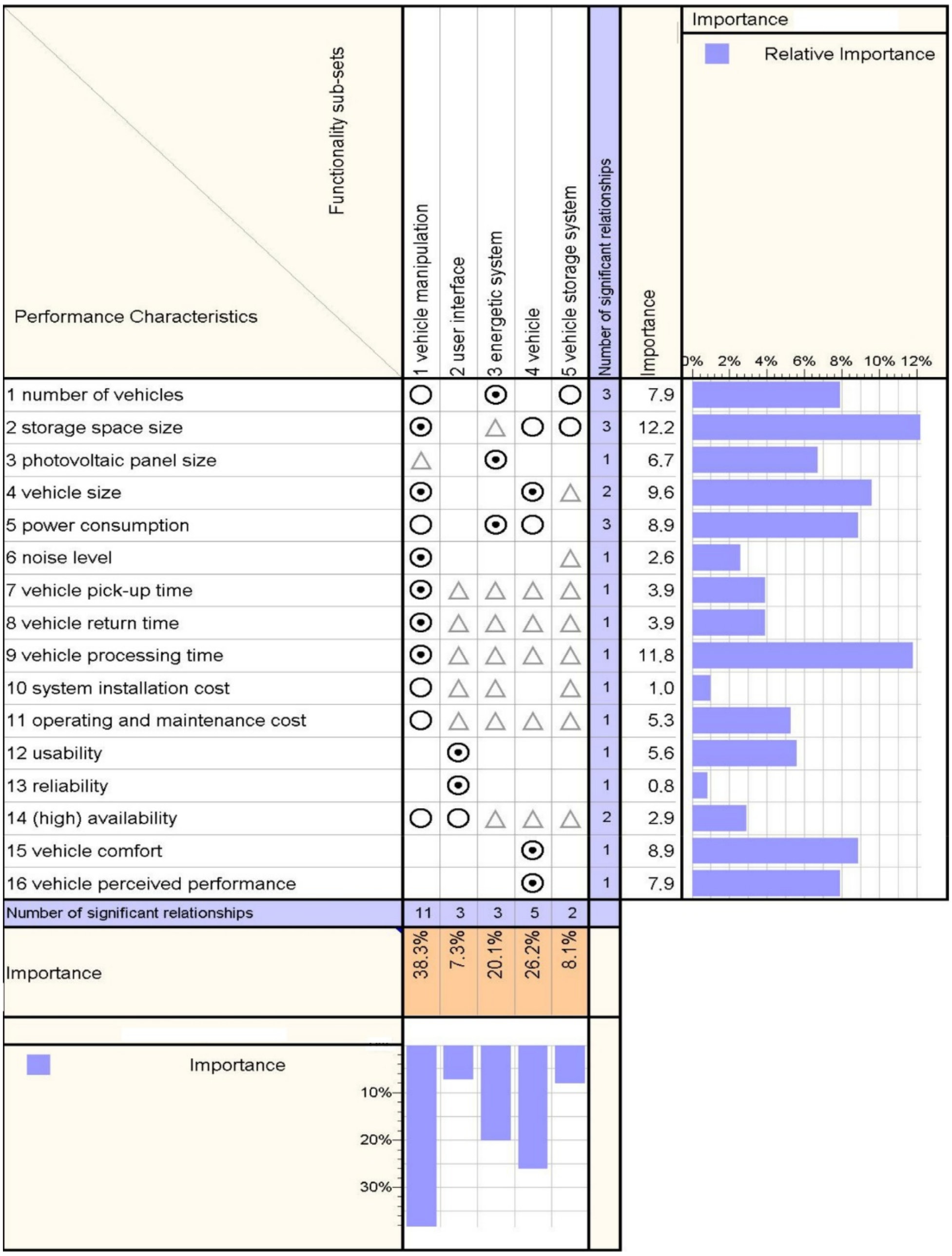

Fig. 4. Functionality analysis using the House of Quality template of the Qualica QFD software tool

The results (the weight of each functionality) indicate the "added value" of each functionality set, both from a customer and a technical perspective. In the analysis above, only the main system functionalities were considered, due to space constraints (the detailed functionality list would exceed 40 items). Fig. 5 shows a more detailed functionality analysis, carried out for the *vehicle manipulation functionality* sub-set (consisting of *storage*, *vertical transfer*, *horizontal transfer*, *positioning*, *transfer between elevator and conveyor)*. Only the relevant performance characteristics were used for the functionality sub-set analysis.

During step 2.5 the main system components were determined and then analysed in relation to the system functionalities. Fig. 6 shows the House of Quality used for the analysis of the components linked to the *vehicle manipulation* functionality sub-set.

The results (the weight of each sub-component) indicate the "added value" of each subcomponent, both from a customer and a functional perspective. Step 2.6 consists of analysing the added value of each sub-component *in relation to its estimated cost* (or implementation effort). In other words, *the investment (financial and human effort) in each component should be as close (proportional) as possible to the added value that it brings to the overall system*.

For completing steps 3.1 and 3.2 the FMEA method was used, but no critical possible failure was identified (for all possible failures, the calculated risk index was below 125).

Based on the information gathered in the previous steps and on a brainstorming session, the final perspective of the *EXPRESS CAR HIRE* concept was formulated (step 3.3). The figures below (including target values for performance characteristics) were set having in mind the importance levels determined through the QFD analyses above. For instance, the value 30 for *vehicle number* was considered to be adequate (i.e. high enough), given the importance level of the characteristic (medium importance) and the need to "score well" on the storage space characteristic (i.e. to reduce the occupied space), on the "vehicle processing time" characteristic (not so many vehicles means a shorter processing time), and on the "vertical transfer" and "horizontal transfer" functionality sets (which have high importance levels). Therefore, the final perspective of the concept consists of:

- **overall performance**: the proposed system will be able to hire 30 compact electric vehicles. To minimize space use, it will be built as a part of an airport terminal wall, as shown in Fig. 7. Vehicle pick-up and return will be done using the graphical interface of the system, after which the complete automated system will provide the customer the requested vehicle (or place the vehicle into the storage space)
- **functional aspects**: vehicle dimensions will be approx. 2.8 x 1.9 x 1.6 [m], in order to accommodate 2 persons and a suitcase, and they will be available in five different colour schemas, smoking / non-smoking preferences, and various battery capacity / autonomy (see Fig. 8). Vehicles will equipped with four 120 kW electric motors, incorporated in the wheels. The energy will be supplied by a Lithium-Polymer battery pack; vehicles will be able to be charged from any existing charging point, by using universal connectors. The hiring process will be simple, without implying any staff, the customer being identified and checked for eligibility through existing means (e.g. credit cards).

Using a touch-screen interface, the user can complete all common operations (requesting the car, returning it, changing some options etc.). The car will be unlocked by using a magnetic card, automatically provided by the system.

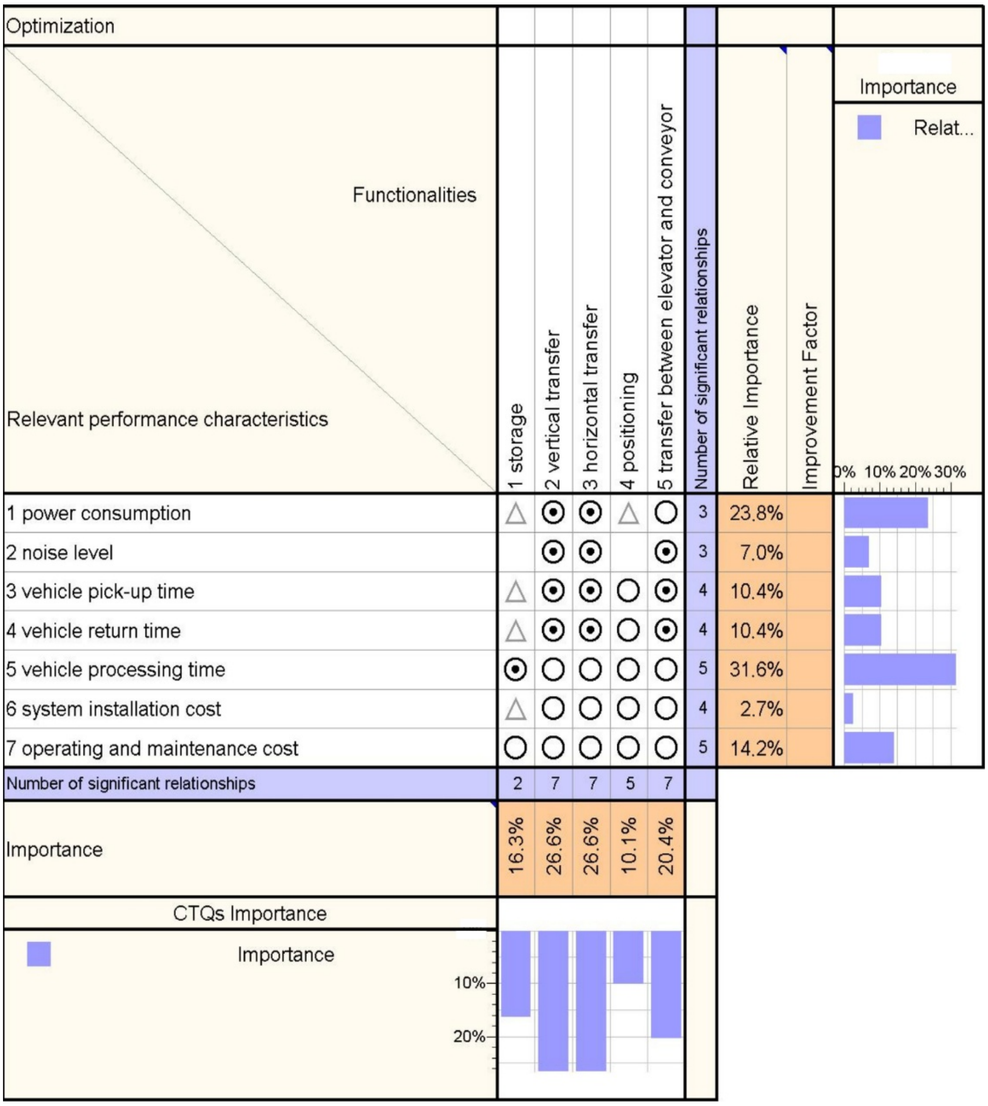

Fig. 5. Vehicle manipulation functionality sub-set analysis using the House of Quality template of the Qualica QFD software tool

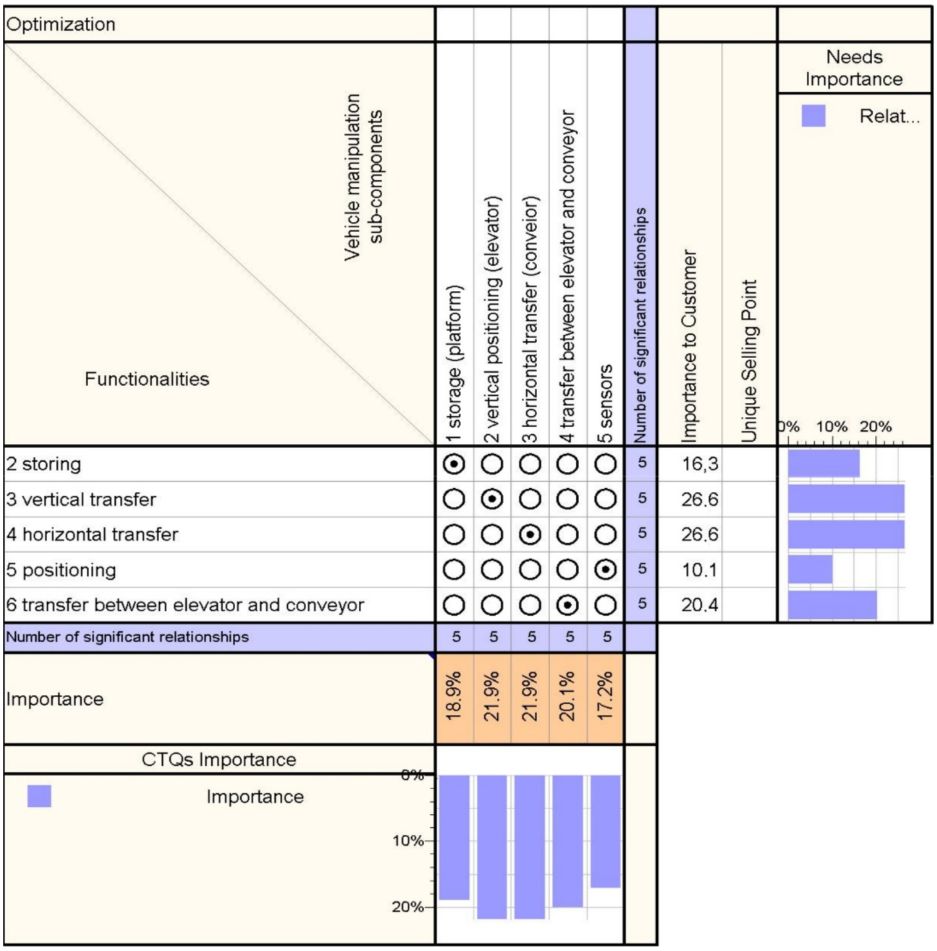

Fig. 6. Vehicle manipulation sub-components analysis using the House of Quality template of the Qualica QFD software tool

Fig. 7. The EXPRESS-CAR-HIRE concept sketch

• **vehicle storage:** the vehicle storing and manipulation system consists of 2 elevators, 5 floors with conveyors and one floor for transferring empty platforms from the vehicle pick-up area to the return area. The transport speed for the conveyors on the 5 floors will be approx. 0.15 m/s, while the elevator speed will be approx. 0.63 m/s. The system will be powered by energy produced by the solar panels located on the terminal roof. After storing vehicles, they will automatically be charged through connectors on the platforms they're standing on

• **environment**: the system can be used at outside temperatures between -10 and +40ºC;

• **life span** (approx.): 50 years for the metallic structure of the building, 10 years for the vehicle manipulation system, 5 years for electric motors, 3 years for the software user interface. The first outage due to errors (without systematic maintenance) should appear no earlier than 2 years. A 2-year warranty will accompany the system;

• **maintenance**: a regular minimal maintenance by qualified personnel should be done. The system will be modular, therefore replacing a component should be done relatively easy and with little cost.

• **eye candy**: all exterior components should be aesthetically pleasant. The structural strength of the storage system will be made of "I" metallic profiles and covered by glass plates. The predominant colour for metallic parts will be Gray. Materials for all visible components should reflect durability and resistance. The vehicle colour schemes will be white, black, red, green, and blue. The noise level should be under 70 dB;

• **ergonomics and usability**: the software that the customer interacts with will be sketched through a specific design-for-usability methodology (Fulea and Brad, 2011). The safety area of the driver when picking up or positioning a vehicle on the platform should be adequate;

• **users and safety**: the target user's age is between 18 and 80 years, with no gender or social category restriction (given one has a valid driver licence). The user should not possess detailed knowledge about the system; in-line help should be provided. The user interface and instructions will be multilingual;

• **patent infringement:** several patents [identified in the EPO and Google Patents databases] regarding electric vehicles, car sharing, and automated parking systems were studied. No patent has been identified that could be infringed by elements of the concept introduced in this paper

• **standards**: the system was developed in accordance to the following standards and regulations: AC No: 150/5360-13 Planning and Design Guidelines for Airport Terminal Facilities, EN 16082:2011 Airport and Aviation Security Services, EN 1090 Execution of steel structures and aluminium structures, the ECC notes on vehicle rental contracts, EN 1986-1:1997 Electrically propelled road vehicles - Measurement of energy performance, EN 81 Norms regarding building and installing elevators, EN 618:2002+A1:2010 Continuous handling equipment and systems;

• **revenue**: revenue will be administered according to commercial partnerships between the system provider and airport administrators.

Some numerical values above were computed within a small-scale technical project in which the authors of this paper were involved; for brevity, the calculations are not reproduced here. However, they should be interpreted as guidelines or starting points for future in-depth analyses.

Fig. 8. The EXPRESS-CAR-HIRE vehicles (sketch)

As a final note, although *EXPRESS-CAR-HIRE* was inspired by the car sharing concept, it may look closer, from an end-user perspective, to a car hiring system, hence its name. Nevertheless, it can be seen as a car sharing system - customers can use vehicles for either short-distance or long-distance travels; they can return vehicles to *EXPRESS-CAR-HIRE* terminals located somewhere down-town or pick up vehicles from an *EXPRESS-CAR-HIRE* station in a city and return them to a distant airport terminal.

5. Conclusions

Although innovative car sharing concepts could be an important step towards reducing air pollution caused by "traditional" traffic, their acceptance (both by society and by transport service providers) needs to grow much faster than the "traditional" traffic itself for the overall carbon emissions to decrease. The methodology introduced in this paper supports the development of a *concept* based on a set of performance characteristics that aim to increase the concept acceptance; it supports an effective "translation" of the performance characteristics into functionalities and components, determining the added value that they incorporate. In this way, adequate resources and effort can be directed *towards those components or functionalities that bring the most added value to the overall product or service*. Of course, the exact figures can be only determined in a more advanced study than the concept design (for instance in an entrepreneurial plan, grant proposal or cost-benefit analysis), but the methodology provides enough data to be used as a relevant starting point.

By including the "eye-candy" requirement among the stakeholder needs, motivation of the younger, more dynamic customers for using an implementation of this concept is envisaged. These key customers usually influence other people, thus quicker extending the customer base.

Regarding the limitations of the proposed approach, the competitive engineering tools used here strongly rely on the talent, creativity and expertise of those who apply them (esp. the TRIZ method), therefore the methodology should be rather seen as a *support tool* for the team of experts that applies it (results cannot be guaranteed). Another aspect worth to be noted is that the more one invests (time and effort) in such an analysis, the more detailed (and consistent) the outcomes are. However, as the methodology helps designing a concept, a balance should be made between how detailed the analysis should be and the *effort* worth to be allocated for (analyzing and) designing the concept.

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