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Conceptualization of an electric inner city transport aid

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Abstract

The E-City Buddy is a small, autonomous, battery driven transport vehicle. It is able to transport goods and make the life of city residents easier, particularly elderly people. Developing such a vehicle is a task that requires a lot of time, manpower and resources. In this paper, we discuss a methodic procedure that allows us to go from a broad idea to a very detailed concept in very short time. These methods not only allow us to define specific requirements but also help structure the product into rough assembly groups. At the end, a pool of solutions for the different assembly groups is worked out and defined. The methods discussed can be used for the development of other small electric vehicles.

Keywords: city electric transport

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1 Introduction

The overall concept of the E-City Buddy (ECB) follows the guiding principles of ecological, economic and social sustainability: (i) it drives purely electric, local emission-free, has a very small space requirement and is intended to be used in a sharing setup. (ii) It is capable of fulfilling partially and fully automated services (e.g. aiding in the transport of shopping goods or packages, as well as autonomous delivery, etc.) and creates more time resources by doing so. (iii) With regard to demographic change, it allows for unrestricted and flexible freedom of movement for people of all ages and for mobility-impaired people.

The development process of the ECB has to be done by only a few people and in a very short time, which is not common for a process of this kind. Therefore, many usual development methods and frameworks, e.g. Scrum, cannot be used. These methods and frameworks mostly require permanent teams with several members and a greater amount of time [1]. To achieve the goal of a defined concept of the ECB in several months, mostly alone or in a team of two developers and without a big financial scope, a linear methodic procedure is carved out and tested in this development process.

The focus of this paper is on the methods that allow requirement analysis and a selection of possible technical solutions coming from a broad idea all the way to a defined concept that fulfills user and use requirements.

2 Requirement analysis

There are four main pillars that describe the ECB: electric, urban mobility, autonomous, transport aid. However, developing a concept based on only these broad requirements is a challenge.

The first step is to set the constraints for the project. It is very important to set the technical constraints and requirements with the help of suitable methods. If the requirements are set wrong or are incomplete, the development process could go in a wrong direction and, in the worst case, fail [2]. Hence, it is essential to methodically develop a requirements list, even if it needs much effort.

To get an idea of how the ECB will work, it is useful to create a use-case scenario first, shown in Figure 1.

2.1 Functional Concept

This use case serves as a functional concept in the development process. It is helpful to create such a use case at the beginning of the development process because the developer has to give thought to the operational area of the new product. So in this step, it is possible to go from several pillars to a rough framework of the ECB.

Having a functional concept allows the requirements, in later steps, to be extracted based on two main points of view. The “user” point of view points out requirements needed by the future users of the product and the “use” point of view is how the product will be used.

The functional concept of the ECB shows the advantages of this approach. By having the use case “transport aid at the supermarket and on the way home”, it follows that there are some basic requirements, for example, “The ECB has to be able to carry a shopping bag” and “The ECB has to be able to maneuver in a supermarket”. However, there are more methods needed to create a complete list of requirements.

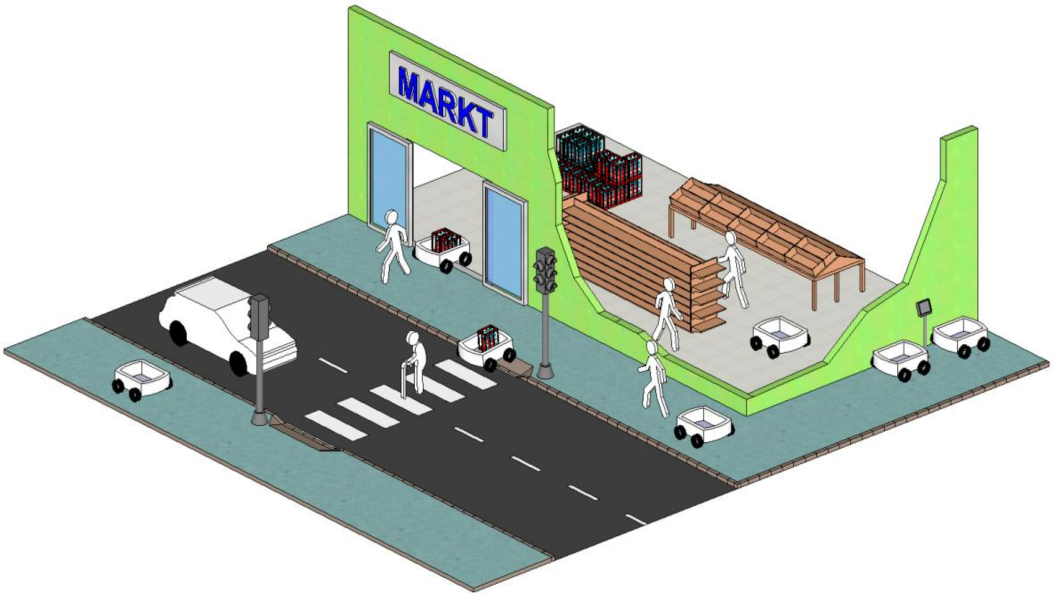


Figure 1: Functional concept of the E-City Buddy in an urban environment

2.2 Requirements List

A requirements list needs to have several properties to be the base of a development process. First of all, it has to cover some key rquirements. To achieve this there are two steps to take. First, the “user and use” (U&U) specific requirements are determined and in the second step, this incomplete list has to be methodically supplemented. The requirements of this full list are finally ranked in a third step to make sure that the development of the product is guided to the right direction [3].

2.2.1 Determining the U&U specific requirements

In general, these specific requirements are determined by many different methods, e.g. marketing specific methods, such as the questioning of “lead users” or the Delphi technique [4]. In addition to these methods, there are the creative methods like the classical brainstorming or the scenario method [3]. It is also possible to work in groups and create ideas and requirements by using group techniques, such as the 6-3-5 brain writing [5].

In a small development process, like in this case, it is not possible to use many of these methods, so the selection of possible courses of actions is limited.

Marketing methods, such as questionings or questionnaires are not possible. There is no money to pay participants and no time to wait for the return of questionnaires. Techniques which are only possible in groups are not useful, either. To sum up, only the creative techniques which are possible in small groups or alone are suitable for the focused processes.

Due to the relatively small amount of required time and the possibility to work alone, it is useful to start the requirements list with the already available **use case** scenario and take the user's point of view.

In this method, it is important to go through an entire use case, as in this example "go shopping" and write down every requirement a customer may have. If possible, it is recommended to create more than one use case, as for the ECB further use cases are "Go for a walk" and "Call a shared ECB".

The use cases alone are not sufficient to get U&U requirements. Whole parts of the life of the new product can be neglected since they are not taken into consideration in the cases. Thus, there are methods needed with a more holistic point of view, for example, **Brainstorming** and **Mind mapping**. These methods are possible if the developer works alone and they can focus on the rough ideas which are already available.

As mentioned, the pillars of the ECB are electric, urban mobility, autonomous, transport aid. For each pillar, a brainstorming pool is opened to collect U&U requirements. A snippet of the resulting Mind map is shown in Figure 2.

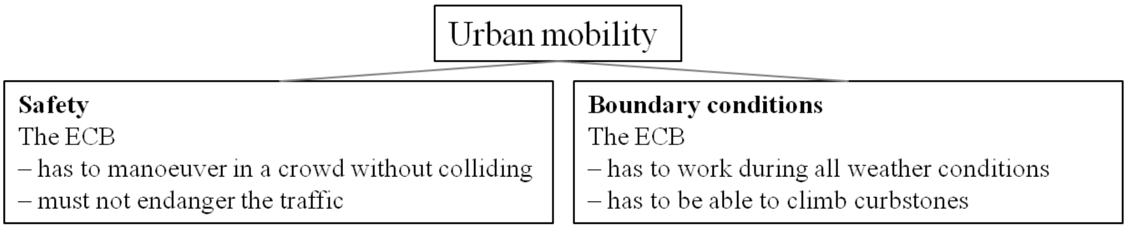


Figure 2: Snippet of a pillar Mind map

After applying these methods, most U&U requirements are determined.

2.2.2 Methodical supplementation of the requirements list

The problem is that many requirements are basic and users simply do not think about them. These requirements are called implicit requirements and it is very difficult to determine all of them [3].

To get a complete list, it is necessary to move from the creative methods to more holistic and structured methods so that the new product is seen as a whole.

A very useful and popular method to cover the whole product life and find implicit requirements is to use a **list of characteristic features**. There are many different lists in literature, but all try to cover all aspects of the lifecycle of a product [3]: Part of such a list can be seen in Figure 3.

For small development processes like the ECB, a list of characteristic features or associations list is very helpful. There is no team needed, it can be done in relatively short time, and in general, the associations challenged by this list yield good results. As shown in Figure 3, many parts of the lifecycle of a product are unknown or not of interest for customers and therefore not shown in the requirements list, yet.

For further research, it is useful to use a **competitor analysis**. Usually, there are products in the market, which have to an extent, similar use cases and therefore similar requirements [2]. The most time-saving process is one already worked out before.

In this development process, it is not possible to actually buy and deconstruct a product, so the only possibility is literature research on the competitor's products. The internet and technical brochures are very efficient sources of such information.

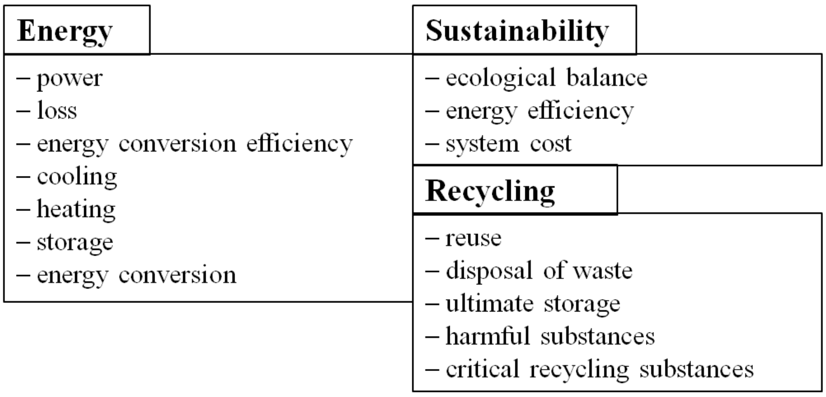


Figure 3: Part of a list of characteristic features [3]

This method is very helpful in this case, too. The ECB has some interesting competitors, all with different purposes but with comparable requirements. Some examples are the *Care-O-Bot 3* of Fraunhofer Institute [6] or the *Arlo* of Parallax Inc [8]. By analyzing the use cases and the way these products are built up, it is possible to fill some gaps in the list of requirements, e.g. the ECB has to fit through a classical door in a flat, like the *Care-O-Bot,* in order to carry the bought goods into the right rooms after shopping. A snippet of the competitor analysis is shown in Table 1. It is important to mention that not all properties of all competitor products can be found, however, the method still gives indications for the developed product.

Table 1: Snippet of the competitor analysis

	Starship	Arlo	Care-O-Bot 3
Transportable load [kg]	9	15.9	10 - 14
Speed [m/s]	1.8	-	1.5
Electric charge (battery) [Ah]	-	7 - 14	60
References	[10]	[7], [8], [9]	[6]

It is often helpful to do **documental research** in the field of the new product to not miss any already elaborated facets of the product class. For example, there are several studies focusing on the acceptance of robots by people or especially by seniors [11]. Out of these studies, some more informal requirements can be extracted, for example, the maximal height of domestic robots, so that they do not scare elderly people.

There are for sure other possible methods and approaches to supplement the requirements list. However, these are only useful with a big financial scope and much time, as is for example prototyping. For our development process, the mentioned simple methods are enough to create a very detailed and complete requirements list.

The next step is to structure and rank the requirements to create a base for the following conceptualization. The following methods to structure and prioritize requirements consume a lot of time per requirement. So if there is a large requirements list, it is almost impossible, alone or in a small group, to include all requirements in these detailed methods in short time. To cover this, it is essential to cut out, for this type of development process, the unimportant requirements.

The goal of this process is to create a detailed, mechanical concept of the ECB. Therefore, all requirements related to software, actual look, charging station or the man-machine interface are excluded from the list of requirements but of course kept for the later and more detailed developing.

It is important to first collect all requirements and cut them in the end because it is possible to get ideas or other requirements out of the later not needed ones, similar to the collection of possible modules later in the process [3].

2.2.2 Structuring and prioritization of the requirements list

Before the requirements are ranked, they have to be formulated in a useful way. The methods to this point do not focus on the proper technical formulation of the requirements, which is very important in the further process to find the right solutions for the given problem [2]. For example, there are requirements on the list like “The ECB has to be able to climb a ramp”. This is not helpful if the needed power of the engine has to be calculated or some other technical decisions have to be made. It would be better if the requirement was “The ECB has to be able to drive an incline of 20%” and so “The center of mass has to be as low as possible to prevent the ECB from tipping over”.

To methodically deconstruct the requirements to their technical base, the **detailing method** is used [12]. This method is simple to execute and there is no need for practice before it is done.

There are other ways to formulate the requirements in a formal way, as the VDA 2006. This method presses the requirements in a standard form to make sure that there is only one way of interpretation for all people [3].

In this process, it is not necessary to use such complicated and not intuitive methods, because only a few people have access to the requirement list and it needs time to profit from these other methods.

An example of a deconstructed requirement of the ECB by the detailing method is shown in Figure 4.

The ECB has to be able to follow a person.
- speed
  - ➔ the maximum speed has to be at least 1.5 $\frac{m}{s}$
  - ➔ the maximum acceleration has to be at least 1 $\frac{m}{s^2}$

The ECB has to be able to carry a big shopping bag and a bottle crate
- room
  - ➔ the loading area has to be at least 450x450mm
- weight
  - ➔ the ECB has to be able to carry 30 kg

Figure 4: Examples of the specification of requirements by the detailing method

This step is very important but also a very part of the whole process. Each value has to come from a reliable source, calculations or from own measurements in order to create a solid base for further calculations. Often documental research is necessary to find studies to get the needed information.

By this stage, the list is complete and there are needed requirements in a technical form, but a list of requirements without a ranking is not enough. There are always conflicts of interest during a development process, but if it is clear what the most important subjects and tasks of the later product are, it is easy to solve them quickly. The ranking also helps workers to get into the project later and to find the direction of the development [3].

There are many possible methods to rank the requirements, such as the “Kano model” or other methods dividing the requirements up into several levels. For this process, the list is divided into **demands and desires** [3].

This classification is very simple and does not need much time, however, it is important and gives an initial view over the importance of the requirements. The big advantage of this method in combination with the detailing method is that the technical requirements directly follow this procedure. All technically measurable requirements classified as a demand are the technical framework for the product and in this case for the ECB.

After this division of the list, there is no real ranking. To achieve this, the method of the **paired comparison** is used for the ECB.

In the paired comparison each requirement is compared with all the other requirements. The more important one gets a point and in the end, all points are added up [3]. The comparison of only two requirements at the same time is easier and more objective than a complete ranking at once.

If possible, these dividing and ranking methods should be done in a team, because of the importance. Based on the sum of the paired comparison, the list is ranked.

2.3 Technical requirements

In Table 2 we show some of the technical requirements that resulted from the previous analysis of requirements which will be the base of the conceptualization phase.

Table 2: Technical Data E-City Buddy

driving range	10 km / 3 hours
negotiable border stone height	50 mm
over passable ramps	20% incline
portable load	30 kg
maximum speed	1.5 m/s
overall dimensions	min: 450 x 450 x 600 mm max: Ø700 x 1200 mm

After the requirements are set and the technical frame is ready, the conceptualization has to be done. To make this easier, it is possible and useful to work out the most important technical properties of the product first by using the **House of Quality**. In the House of Quality, it is possible to rate the properties using the already worked out technical requirements [2].

In this small development process, the main matrix of the House of Quality is the most important part. The comparison with competitors' products is also possible if a competitor analysis was done before.

This method needs much effort, but it includes some big advantages in the later stages of the process. In fast processes with no financial scope like in this one, it is important to focus the given resources on developing the most important parts of the new concept to show its advantage even as a concept. The main matrix of the House of Quality produces this needed ranking. In addition to focusing on the important parts, this ranking can also help to solve possible conflicts of aim. So in this process, the main matrix of the House of Quality is used.

3. Conceptualization

3.1 Functional structure

After defining the functional and technical requirements and the most important technical properties, the conceptualization phase starts by analyzing the functional structure of the product [3]. The goal of a functional structure in this development process is to roughly divide the ECB into the most important modules.

There are two main possibilities to get a functional structure. First, there is the Input-Output-View, which describes all inputs and outputs as a mathematical formula [3] and second, there is the **hierarchical view**, which divides the main function through several stages up into its sub-functions [13].

The Input-Output-View is most useful if the flow of goods is one of the main tasks of the product [3]. So in this development process, the hierarchical view is more useful, to be able to control the complexity of the tasks of the ECB.

To ensure a clear arrangement and formulation of function, it is useful to describe each found function and sub-function by several keywords. There are some different possibilities to describe the functions, such as the "substantive-verb-substantive" method or the "substantive-verb" method [13]. To describe the ECB and be faster at building a functional structure, the "substantive-verb" method is used, in which each function is described by a substantive and a verb. By this method, the function is not only named, but it is also described what is done, and how. A small portion of the functional structure of the ECB is shown in Figure 5. It can be seen that through this analysis of the product, the necessary modules are a logical consequence. It is for example obvious, that there needs to be a module generating a force to decelerate the ECB and one to generate an acceleration force to make the movement possible.

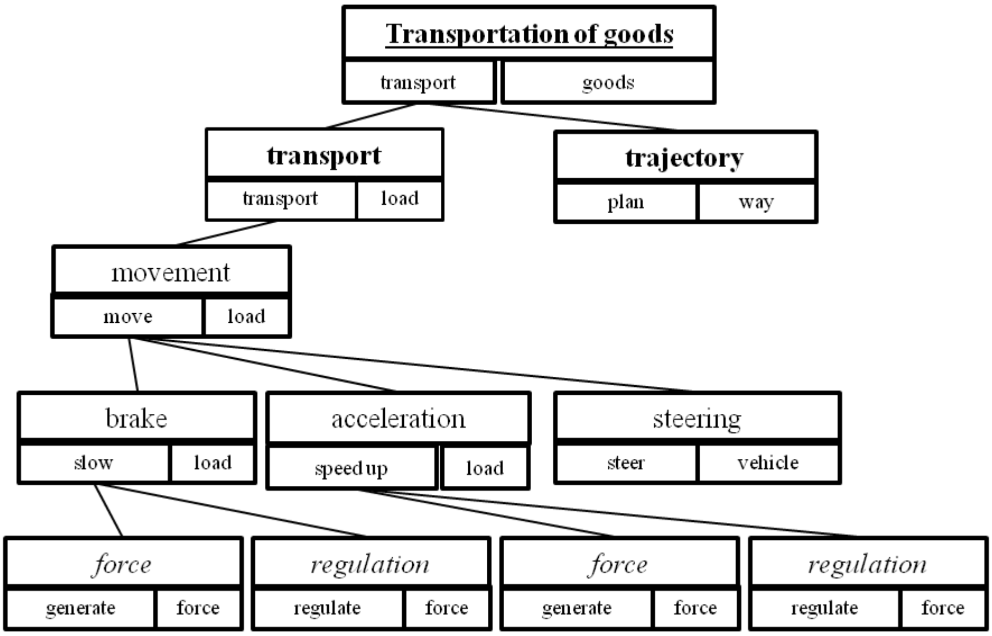


Figure 5: Part of the functional structure of the ECB

3.2 Creating a pool of solutions

The next step is to create possible technical solutions for the defined modules. To find the optimal solution regarding the developed product, it is necessary to find as many as possible known solutions for the module at first. The ranking and selection of the solutions have to be done after the pool is complete, in order to avoid cutting out unusual but maybe productive and good solutions [3].

Several methods, which are used to simply collect possible solutions, have already been discussed in the previous chapters, like **Mind mapping** or the **competitor analysis**. These methods are still very useful and create a view with a wide variety on the regarded module. Hence, they are used in this development stage for the ECB as well.

Additionally, there are many **books** that give an overview of common and future solutions, like for braking systems [14] or for energy storage and battery technologies [15]. In a small process like this, such books are very helpful and can save a lot of time. Besides giving possible solutions for specific modules, they also often contain important information about how to dimension these solutions. Especially in small teams or individually, it is not possible to have detailed knowledge of all aspects of such a complicated system like a small, autonomous vehicle. So, in this development process, books like these helped a lot to create and dimension the concept of the ECB.

The found possible solutions are put together in a Zwicky-Box to get a clear view of the possible systems and combinations. A part of this box is shown in Table 3.

Table 3: Part of the Zwicky-Box of the ECB

	Solution 1	Solution 2	Solution 3	Solution 4
Engine type	Synchronous motor	Induction motor	DC motor	Reluctance motor
Braking system	Disc brake	Drum brake	Electric retarder	Regenerative braking
Energy storage	Li-Ion battery	Molten-salt battery	Nickel–metal hydride battery	Supercaps

3.3 Ranking and selection of the used solutions

To get the optimal concept of the product, the defined technical solutions have to be rated and ranked regarding the defined requirements. There are many possible methods to rank the found assemblies. In this development process, two of them are used.

First of all, it is useful to write down the advantages and disadvantages of each technical system [3]. This simple **trade-off analysis** seems to be rudimentary and demanding, but it is essential for the development process. It is important to know enough about the possible technical solutions to be able to really rate them, which is hard, especially if only one person is working on this project. Therefore, the literature research which is necessary to get the needed information on all the solutions, and which is forced by this trade-off analysis, is very important.

The second advantage of this approach is that the vision of the developed product becomes clearer during this method. For example, one question is, “Why would it be useful or not to have only two wheels on the ECB?” To answer this question, several small use cases have to be thought-out, like “What happens if the software fails or the battery runs out?” It is obvious, that the ECB would tip over and it would not be possible to keep the load safe anymore, for example, the glass bottles from the shopping could break and cause some damage. So during this method failure analysis has to be thought-out which clearly helps in the later ranking and the further development process to recognize, analyze and minimize possible disadvantages of the product.

Although useful, this method does not allow a real ranking, so there has to be another methodical step. This is done by using a **cost-utility analysis**. In contrast to simple ranking methods, like the paired comparison, where only full systems can be compared, the cost-utility analysis is able to rank complex systems with many ranking criteria. To achieve this, these criteria are developed in a structured and hierarchical process. The criteria are developed out of subject areas and the worked out characteristics are compared only with the other ones, coming out of the same area. The importance is ranked for each group on its own, to get a sum of all importance rankings equals 1 in each group. In the end, all group rankings are multiplied to get the final value of the criteria for the ranking [3].

The development and the rating of the criteria for the braking system are shown in Figure 6. On the right, there is the group importance rating and on the left, there is the final result. Below, the braking system is used to show how the modules are selected.

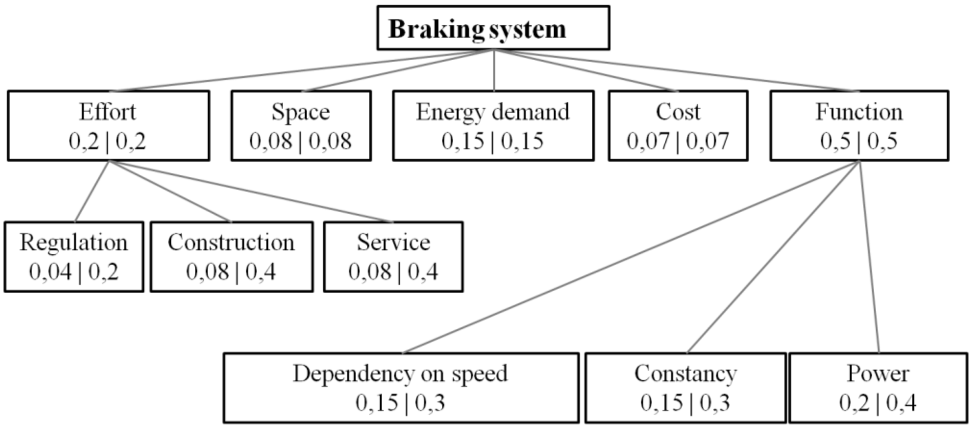
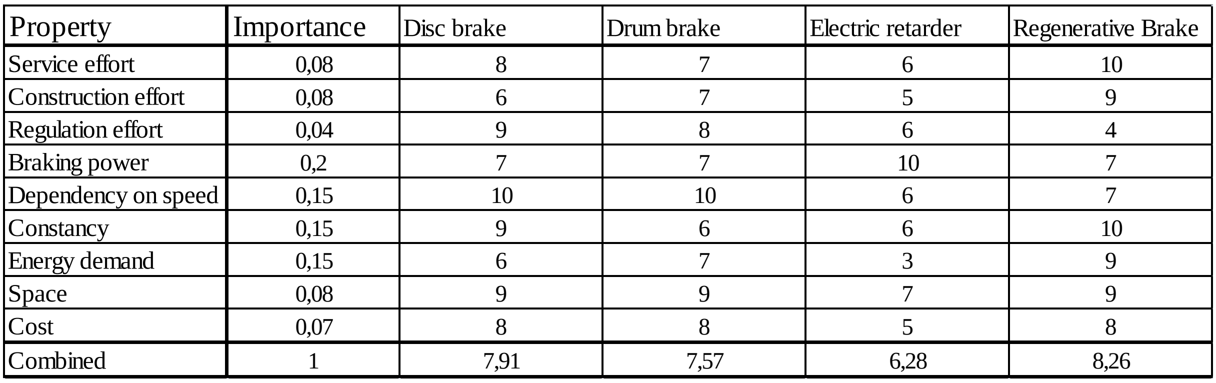


Figure 6: Development and rating of criteria to rank braking systems.

With the help of these properties and importance rankings, the found solutions can be rated to select the best one.

The ranking is done by using the method of weighted point rating which is part of the cost-utility analysis. In this method, all properties of all possible solutions are rated, e.g. from 1 to 10, multiplied with the importance rating of the property which was worked out in the previous step and finally added up to a final rating [3].

An example for such a rating is shown in Figure 7.



Property	Importance	Disc brake	Drum brake	Electric retarder	Regenerative Brake
Service effort	0,08	8	7	6	10
Construction effort	0,08	6	7	5	9
Regulation effort	0,04	9	8	6	4
Braking power	0,2	7	7	10	7
Dependency on speed	0,15	10	10	6	7
Constancy	0,15	9	6	6	10
Energy demand	0,15	6	7	3	9
Space	0,08	9	9	7	9
Cost	0,07	8	8	5	8
Combined	1	7,91	7,57	6,28	8,26

Figure 7: Final rating of the braking systems

Of course, no ranking is entirely objective, but by using the cost-utility analysis it is possible to systematically compare few characteristics of the module and rate each property on its own. Because of this, this procedure leaves only a little space for subjective decisions. Thus, this time-consuming method is worth the effort in this development process. To avoid unnoticed discrepancies between the proposed concept and the requirements, it is essential to always check the results of a ranking or a rating again after finishing. There is no team to correct a mistake in such a small development project, so this step is even more important here.

3.4 Assembling a concept

After ranking all the possible, technical solutions with the shown methods, it is possible to assemble a concept out of high ranked solutions. Often, it is not possible to simply put together all the best-ranked solutions to get the best concept. Several solutions may not be able to work together, as for example, in the ranking for the ECB four usual wheels and a differential drive is ranked highest. To use a differential drive, two wheels have to be replaced by casters to enable the steering. It would also be possible to replace all four wheels through Omni wheels or Meccanum-wheels, or to simply use two instead of four wheels.

Due to these conflicts, several concepts have to be designed and ranked with the cost-utility analysis once more.

At the end, the ECB is built up out of the highest ranked concept out of four possible ones. The specifications of this concept can be seen in Table 4.

Table 4: Final concept of the ECB

Wheel arrangement	Four wheels, classical setting
Type of wheels	Two Casters, two standard wheels
Steering	Differential drive
Type of motor	Permanent magnet synchronous motor
Number of motors	Two
Packaging	Plastic film
Wheel suspension	Solid axle
Springs	Helical spring
Braking system	Regenerative brake
Transmission	Gear
Lubrication	Fat lubrication
Structure	Space frame
Shock absorber	None
Charging system	Conductive
Parking brake	Block-brake

Based on this concept, in a first step, the most important components are dimensioned and selected, like the engines, the wheels and the framework. The first constructive result is shown in Figure 8. This result was achieved by a team of two persons and three months of work. Within these three months, the methodical procedure, the requirement analysis, the component research and the construction were done.

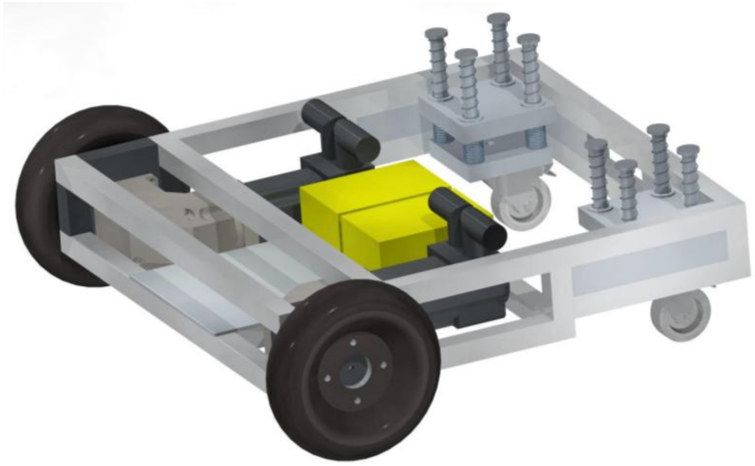


Figure 8: First constructive vision of the chassis of the ECB [16]

3.5 Further development

It is obvious that this first concept is not optimal or ready, for example, the suspension of the casters is solved in a complicated way.

The advantage of the used methods is shown in the further approach of this project. In the further development, the competitor analysis, the trade-off analysis, and the cost-utility analysis are used to develop the chassis further. Besides this, a vertically adjustable platform is created using the same methods to ease the lifting of the shopping goods out of the ECB and to lower the center of mass [17].

The actual state of the ECB can be seen in Figure 9.

Figure 9: Actual state of the ECB with platform and adjusted Casters [17]

4. Summary and Outlook

In this paper, a linear development methodology is discussed, which is able to create a detailed concept of a product, as shown in Figure 9. This way of development is very useful if the project has to be completed individually or in a small team in a short period of time and with a limited financial budget. The base of this process only has to be a vague idea or a few keywords. The ECB was developed to the shown stage mainly by three people without a significant budget in only five months.

To achieve this goal, the methods build upon each other to create a logical path and a solid frame for the development.

The first step is to come from the bare idea to a complete set of ranked requirements. This goal is achieved by first using creative methods, such as Mind mapping or use case analysis, and second to filling the gaps with more structured methods, such as the list of characteristic features or competitor analysis. To rank this list, the requirements are formulated using the detailing method and ranked by the division in demands and desires and the pairing comparison.

In the second step, possible technical solutions for the needed modules, found by the functional structure, are collected and ranked at the end. To collect possible solutions, similar methods as in the first steps are used, like Mind mapping or documental research. The final ranking is done by a trade-off analysis and a cost-utility analysis.

This process seems to be cumbersome and too complex, but in fact, it is important to structure the development process to avoid mistakes or subjective decisions when working alone. The regarded product is a complex assembly of mechanical and electrical devices and the methods allow it to keep the overview of the whole project. Additionally, all these methods are simple to understand and not too time-consuming for one or two developers.

It is imaginable to use this framework to develop concepts as a trainee or a student writing a thesis, as well as to quickly figure out if an idea of a product fits into a company's range of goods and if it is reasonable to use more resources for further development.

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