STAND-BY MOBILITY DEVICE FOR LOCAL PURPOSES

R.G.A. van der Wee - July 2010

TUDelft

Stand-by Mobility Device for Local Purposes

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End date:	2010, July

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Preface

This report is part of the “Stand-by Mobility Device for Local Purposes” graduation project, and functions both as an exploratory study to the subject and an explanation of the design steps made during this process. The graduation project is the final assessment of the Integrated Product Design (IPD) Master at the Delft University of Technology.

The project is partly accomplished at the Corners and Curves design studio in The Hague; Philippe Soeters was representing this company. Due to some disagreements on fundamental aspects of this graduation project I decided to end the cooperation with Corners and Curves before finalising this project. The TU Delft supervisory team exists of Ir. S.F.J. Flipsen (chair) and A.H. Jellema (mentor).

The purpose of this report is to gather information about mobility, market and consumers relevant to the subject of short distance mobility (0-1 km) in combination with a local purpose (supermarket visiting). On behalf of the collected information conclusions will be drawn, design criteria can be formulated and further steps onto the actual product development can be made. This report also explains the design steps, and methods that are used during this design process. The report finalises with a final design proposal and recommendations for further improvements.

The analysis phase of this report is also handed in as the final assignment of the Industrial Design Master course “ID4190 - Preparation for Graduation”.

Summary

This graduation project focuses on the design of a “Stand-by Mobility Device for Local Purposes” (SMDLP). The SMDLP is a multi-functional mobility device, designed for supermarket visiting. The concept can be best imagined as a fusion of a carrier cycle, shopping cart and baby stroller. Namely the SMDLP has three comparable configurations: (1) cycling - riding mode, (2) shopping - walking mode and (3) storage - stand-by mode. This enables people to use the same device for both transportation and supermarket visiting.

This idea of combining three yet existing functionalities into one device came forth from the idea that current transportation means are lacking in efficiency in case of supermarket visiting. (Travelling by car may cause traffic-jams, environmental pollution and fatal accidents; using the public transport may result in delays and by riding a bike one is unable to transport bigger loads safely; walking requires a lot of effort and time).

In case of supermarket visiting people have to decide whether they go by car, public transport, bicycle or walk to the supermarket. Especially citizens, living in highly urbanised areas are limited in transportation abilities; because of limited parking space for cars and bicycles, busy travel routes and crowded supermarkets.

The SMDLP intents to be the alternative: the device is ‘dedicated’ to supermarket visiting. People living in highly urbanised areas could use the SMDLP to transport (over short distances of 0-1km) themselves to the supermarket, gather shoppings (average is 7,5 kg and max 15kg) inside the supermarket, cycle back home and take the SMDLP along inside when storing the shoppings in the fridge or closets. The SMDLP can be folded into a compact package so people are able to store the device itself; ‘stand-by’ in the hallway, balcony or in any desired room.

The SMDLP has been enriched, in terms of creating a more ‘intelligent’ product by implementing both (1) a rental system and (2) a payment system. When implementing a payment and rental system, the main idea would be to sale the SMDLPs to the supermarket (guarantees high sale quantities) and implement some sort of customer bonding; users can freely make use of the supermarket’s SMDLP rental system (no cost of ownership for consumer) but are bond onto that one specific supermarket chain when using its transportation mean. With this system supermarkets can transform into a new formula where less conventional shopping cart, car parking spaces and bicycle racks are needed.

1. Introduction

The Corners and Curves design agency is a multidisciplinary design company active in the fields of interior, graphical and product design. The company was founded in 2003, as part of the Advanced Industrial Design Engineering program on the University of Technology Delft.

Founders Philippe Soeters and Marinus van Diggelen continued working together because of previous successes after they got their MTD (Master of Technological Design) degree. Within the discipline of product design Corners and Curves shows great interest in new mobility concepts. One example is the Dadanana JoinUs which in fact is a multifunctional fusion between a baby carrier and a backpack. The other example is the Travelteq suitcase which is a fusion between a normal suitcase and a seat.

The mobility market is growing, and shows the upcoming of new products in the appearance of innovative tricycles, kick scooters, foldable bicycles, strollers, etc. More and more 'dedicated products' are launched onto the mobility market, which are strongly connected onto some specific purposes, and therefore can be more effective in its use. Corners and Curves sees opportunities in this marketing trend and want to extend their mobility product line with a new type of personal vehicle for shopping purposes.

1.1. Problem definition

Mobility is a keystone in nowadays modern society, and can be defined as the movement of people from one place to the other within a certain time frame. The field can be divided into infrastructure (network), traffic device (tool) and the purpose (motivation).

People feel the need to be mobile, because it supports both psychological and financial wellbeing. Although mobility may be growing, it has some downsides and may be lacking in efficiency in some situations. People are aware of the downsides that come with certain traffic devices. Travelling by car may cause traffic-jams, environmental pollution and fatal accidents; using the public transport may result in delays and by riding a bike one is exposed to the weather conditions and unable to transport bigger loads. Being mobile at most profitable way requires proper decision making, because in every situation people can choose between several available transportation means.

In case of supermarket visiting the mobility problem becomes more visible and tangible; people have to decide whether they go by car, bicycle or walking to the supermarket. Especially citizens, living in highly urbanised areas are limited in transportation abilities; because of limited parking space for cars and bicycles, busy travel routes and crowded supermarkets.

Most people who are living in the highly urbanised areas inner cities do make use of a bicycle to visit the supermarket or go walking. Most people decide to walk when the distance to overcome is less than 500 m *[CBS 1999]*, but when they also have to bring some relative heavy belongings along they decide to go by bike or car even. The other way around people do not like to prepare a transportation device before using it because it requires too much effort. What is the use of getting your stored bike from the shed for such a short distance, and loose a lot of time while doing that?

In other words short distance mobility devices are lacking in additional functionality and therefore people often do decide to use long distance transporters, like the car, instead. The determination of this behaviour shows that there is a need for a mobility device for local purposes that is more widely applicable.

1.2. Assignment

The graduation project focuses on the design of a "Stand-by Mobility Device for Local Purposes". The device is an attribute for supermarket visiting, and therefore should transport one person with some shoppings. The device is "stand-by" and therefore independent from bicycle racks and parking spots, making it able to bring the vehicle along inside the supermarket or at home. The design outcome also has to match ergonomic standards, and there should also be attention to sustainable product development and efficient production techniques.

The project will result in a concept design which is elaborated in a 3D CAD SolidWorks model; this model will present the aesthetics and functionality of the concept. The functionality will also be validated in a working prototype. Furthermore the findings from the project will be described in a final report, containing the different phases of the design process. The outcome of the project will be presented in an A1 poster and an oral presentation.

2. Mobility analysis

"Mobility has been defined as the potential for movement, the ability to get from one place to another" *[Handy, 2002]*. In this chapter the current mobility situation of people living in urban area's will be discussed. Topics which are relevant are the way people live, their need of being mobile, their experiences with mobility and how to make mobility more sustainable. After this "Mobility analysis" a better insight is gained in peoples personal and society's problems relevant to mobility.

2.1. Urban Mobility

Living in the city is very popular nowadays, and because of this urban area's are growing extensively, this process is called urbanisation. The United Nations defines urbanisation as movement of people from rural to urban areas with population growth equating to urban migration. *"UN says half the world's population will live in urban areas by end of 2008"* *[IHT, 2008]*.

Urbanisation occurs naturally from individual and corporate efforts to reduce expense in commuting and transportation while improving opportunities for jobs, education, housing, and transportation. In cities there are also better basic services as well as other specialist services that aren't found in rural areas. For example health is one of the major factors; there are doctors and hospitals that can cater for peoples health needs. Other factors include a greater variety of entertainment (restaurants, movie theatres, theme parks, etc) and a better quality of education, namely universities.

As mentioned before 50% of world's population is living in urban area's at the moment, and is inevitable increasing. In the Western World people are used to live in cities for decades. North-America is the most urbanised continent, 82% of the population lives in urban area's and Europe is second with approximately 70%.

People share in their daily life the same space, and for their mobility the same infrastructure. The density of population within the cities is increasing resulting in numerous of problems relevant to mobility. *"Throughout Europe, increasing traffic in urban areas leads to permanent congestion. This has negative economic, social and environmental impacts and degrades the built environment"* *[EC, 2007]*.

On average a European citizen makes 1000 trips per year and half of these are less than 5 km long. The car is by far the dominant urban mode, contributing about 75% of kilometres travelled in EU conurbations. Increased car use has been accompanied by safety and environmental problems, as well as by a downward spiral of under-investment in public transport. Public transport is an important alternative to the car. It plays a major role in the bigger cities where it carries 2.5 – 3 times as many people as private transport. For many of the shorter trips walking and cycling could be a true alternative.

"*The most significant factors driving demand for mobility in the twentieth century are the rapid growth in the number of people in the world, their steady migration into cities, and the decline in the population density (inhabitants per square kilometre) of these cities*". *[WBCSD, 2001]*

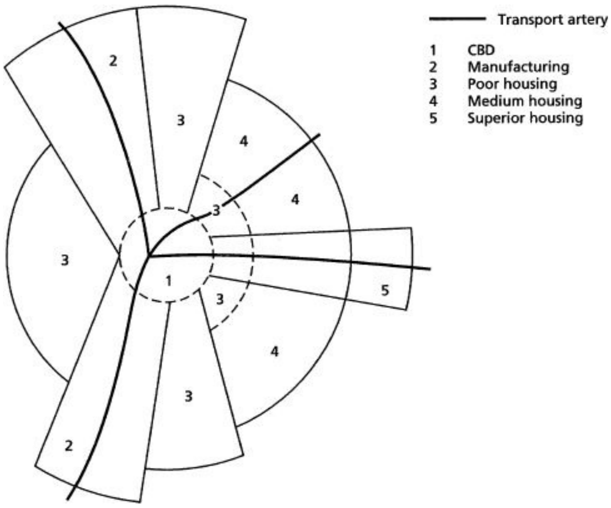
Conclusion

•Because of increasing urbanisation, density of population within cities is increasing; resulting in more congestion and environmental pollution, this because the car is by far the dominant urban mode of transport.
•Walking and cycling could be a true alternative for shorter trips (like supermarket visiting); it is less sensitive for congestion and environmental friendly.

2.2. Necessity of mobility

Mobility is a necessity for people living in cities because this enables them to reach certain facilities who can provide in the basic needs of clothing, foods, education, jobs, etc. Those facilities are established onto specific locations within a city according to a certain structure. A model that explains and describes the existence of this inner structure of a city is the Hoyt Sector Model.

According to Hoyt *[Hoyt, 1939]* a city exist of a central business district (CBD) and surrounding wedge-shaped sectors which expand outward from the city centre along railroads, highways, and other transportation arteries. Hoyt observed that it was common for low-income households to be near various public transportation routes into an urban area, including railroads, sea ports, and tram lines. Public transport is very important for estimated 40% of EU households who do not have a car. The sector of low-income housing is bordered onto manufacturing sectors (traffic, noise, and pollution makes these areas the least desirable) while sectors of middle- and high-income households were located furthest away from these functions. Hoyt's model attempts to broadly state a principle of urban organization.



The Hoyt Sector Model attends why for instance shops, pharmacies, schools and supermarkets are located in certain sectors. Because of the insight the Hoyt model gives, it becomes clear that people always have to move from one sector to the other in order to satisfy in their cumulative needs. In today's busy life a good accessibility of daily supplies and services is essential. The presence or immediacy of daily supplies and services is one of the key aspects which contribute to the quality of the living environment.

In order to test the accessibility of the living environment the Central Bureau of Statistics (CBS) in The Netherlands investigates which percentage of the population does have access to the elementary facilities like the supermarket, a primary school and the pharmacy. Less than 10% of the Dutch population has access to a supermarket, a primary school and a pharmacy all within a region of 400 meters (5 minutes walk) from their homes. 20% of the population has access to two of the three facilities within the 400 meter region and 32% only has one of the facilities within that reach. 38% of the overall Dutch population has to travel further than 400 meters in order to reach a supermarket, a primary school or a pharmacy in particular. In cities the amount of people that has to travel further than these 400 meters is, of course, less than those who are living in the rural area's. In very strongly urbanised area's 17%, in strongly urbanised area's 33% and in feeble urbanised area's 40% of the citizens does not have one of the facilities within 400 meters.

"Today, two overarching phenomena are shaping the pattern of human settlement. The first of these is urbanization — the tendency for populations to concentrate in cities. The second is decentralization — the tendency of these same urban areas to expand outward, generally at rates faster than overall population growth, producing net declines in the population densities of metropolitan areas. Neither of these phenomena could be occurring without increased mobility". [WBCSD, 2001]

Conclusion

•In highly urbanised areas (cities) distances to certain facilities (supermarket) are shorter than in less urbanised areas (rural area, suburbs) – therefore more people should be able to make use of the "Stand-by Mobility Device for Local Purposes" in cities.

2.3. Supermarket visiting

Supermarkets do execute numerous of consumer researches in order to gain a more thorough insight about people's mobility behaviour in relation with supermarket visiting. In conversation with a region manager of Super de Boer supermarkets *[SdB, 2009]*, an insight about consumer mobility behaviour at three big cities in the Netherlands (Amsterdam, Rotterdam and Utrecht) is gained.

First of al it is important to understand the differences between inner city supermarkets and suburb supermarkets. Typical inner city supermarkets are located inside the city centre, were space is scare and the urbanisation rate (amount of households per square kilometre) is very high (more than 2500 households/km2). In the suburbs (less than 1500 households/km2) there is more space available for car parking and bicycle racks.

In the following we take a deeper look into visitor's mobility behaviour; a comparison between typical inner city supermarkets and the ones that are located in the suburbs will be made. Most interesting is the way people use transportation means in order to visit the local supermarket. It is also very useful to understand peoples emotional state about subjects relevant to their way of transport; like available parking spots, presence of bicycle racks and the amount of free space in the supermarkets shopping paths.

A lot of people (app. 40%) who are living at the inner city area do not have a car, and only app. 4% of the supermarket visitors do make use of the car when visiting the supermarket at the city centre. Car visitors are quite negative about the amount of available parking spots at inner city supermarkets. In addition app. 70% of the visitors of inner city supermarket will go walk and app. 26% does use the bicycle instead. Also bicycle visitors are quite negative about the bicycle parking possibilities, people state their should be more bicycle racks available. In contrast a supermarket in a suburb area provide more possibilities for car visiting, in such areas app. 38% of the visitors go by car. Car visitors are positive about the amount of available parking spots, this might be one of the main reasons why many people at the suburbs do take the car to visit a supermarket. Also in these areas cyclist represent app. 26% of the visitors, and like inner city supermarket visitor they find supermarkets are lacking in the amount of available bicycle racks. Big difference is recognised in the amount of people, app. 36%, that go walk to the supermarkets in suburb areas in comparison with supermarkets located at the inner city. In both situation; at inner city and suburb visitors are positive about the amount of space at the supermarket's shopping paths.

Transportation means	Amount of participants	Average age	Average distance	Average mass	Average frequency
Car	9	45 years	1255 meter	20,2 kg	2-3 times a week
Bicycle	12	35 years	1016 meter	7,8 kg	2-3 times a week
Walking	6	34 years	580 meter	4,2 kg	2-3 times a week

Transportation means in relation with distance from home and mass of shoppings.

In addition (See table above) the average ages, distances, masses of shoppings and the visiting frequencies per transportation device were investigated (Internet questionnaire, 27 participants: *[Appendix, I]*). The distance to overcome per supermarket visit by car (1255 meter) or bicycle (1016 meter) is more or less the same, however the average mass of shoppings people are able to bring along do defer; car 20,2 kg and bicycle 7,8 kg. People who are walking in order to visit a supermarket travel way less (580 meter) and also buy less (4,2 kg). The average age of people who travel by car to a supermarket (45 years) is higher than the average ages of people who travel by bicycle (35 years) or go walking (34 years), although the average visiting frequency is more or less the same for all transportation means (2-3 times a week).

Conclusion

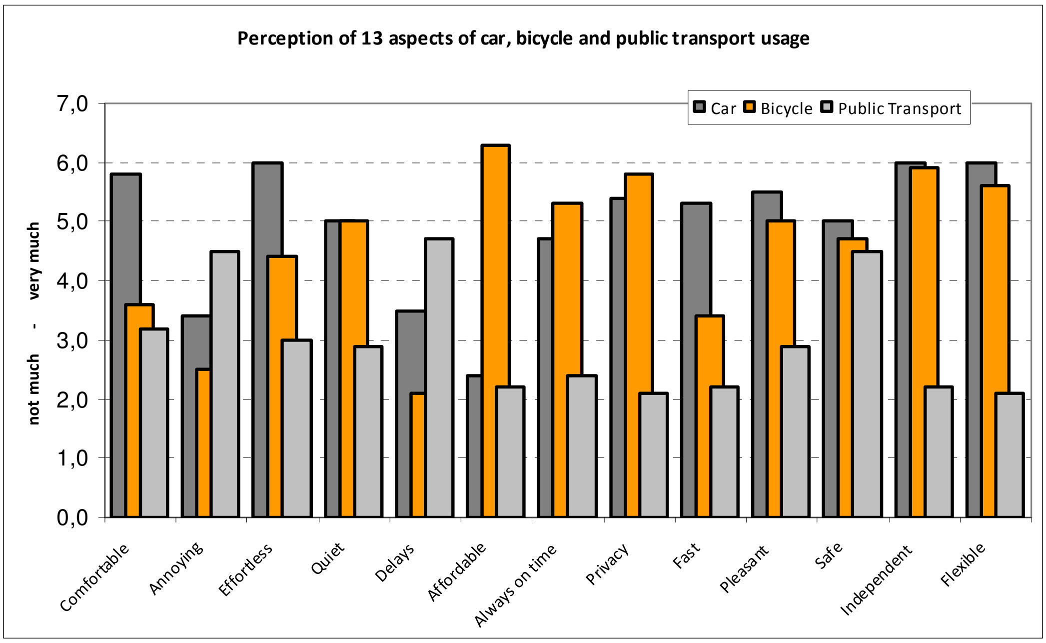
•A mobility device which is independent from car parking spots and bicycle racks might be profitable for supermarket visitors.
•There is enough space inside the supermarket's shopping paths to take such a mobility device along inside the supermarket (assuming that the dimensions of the device are smaller than an average shopping cart).
•Car and bicycle visitors travel over comparable distances, but with a car one can bring more shoppings. Cycling to the supermarket might be more attractive to consumers when it is possible to bring more shoppings back home.
• People who are walking to a supermarket travel over shorter distances and bring less shoppings back home; enabling walking visitors to bring more shoppings, with less effort, might be profitable for consumers.

2.4. Experiencing mobility

Although mobility itself is a necessity, the option to travel with any kind of traffic device is not fixed. Mobility brings many benefits to the population, but also has its downsides. Congestion, delays, environmental pollution and accidents are some of the many downsides which all have an influence on experiencing mobility. People do experience mobility on hand of the merge of the forehand expectations and the resulting outcome of a certain traffic device. To be able to compare different types of traffic means and to identify the underlying problems and benefits the subject of mobility will be dived into; ***travelling by car***, ***public transport*** and ***bicycle***.

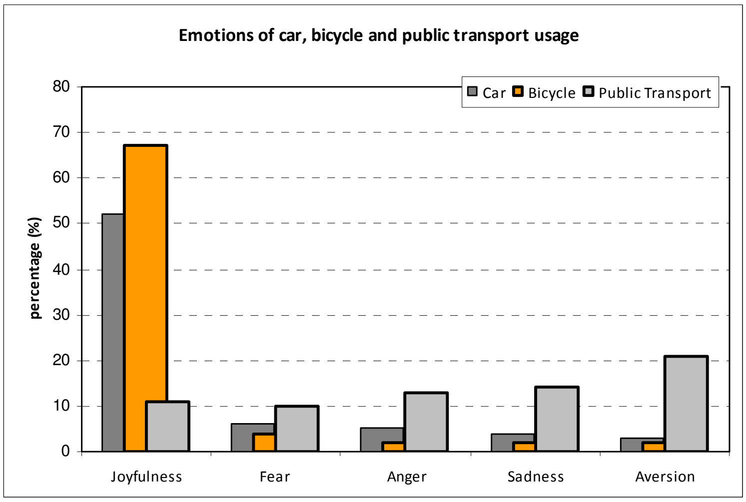
Two-thirds of all Dutch inhabitants (67%) says that they believe the car is the most attractive traffic device. The bicycle is represented by more than one quarter (27%), and the public transport only by 4% of the Dutch population. From the Dutch who find the car is most attractive for daily travelling (commuting to work), more than two third (70%) finds the bicycle the second best alternative. Why these traffic means deviate so strongly in popularity will be put forward by the problems people do encounter while using them.

The biggest problem people encounter during ***travelling by car*** concerns the annoyance on the behaviour of others. Next are the costs involved with daily car travel and the delays as a result of congestion (mainly caused by traffic lights). Unexpected is the fact that the daily traffic jams are much less often identified as a problem. This because there is a clear difference between what people see as a problem for society and what people experience as a personal problem. Thus, especially traffic jams are identified mostly as a social problem, and barely as a personal problem. *"More than half of the commuters (52%) who daily travel by car to and from work has no problems with the daily traffic jams. Personally people are more disturbed by the (aggressive) behaviour of others: almost one third (29%) of home-work commuters will see this as a (serious) problem" [Harms et al., 2005]*. Although all the above described disadvantages the car is most favourite because of its comfort, ease, independence, flexibility and also because of the speed and pleasure it provides (see table below).



Source: Harms et al. 2005

Most mentioned problems relevant to ***public transport*** refer to the costs involved and the reliability of travel schemes. 44% of the people who frequently travel with public transport state that the high ticket prices are one of the biggest problems. The delays are mentioned by 42% of the travellers as a serious problem. Nevertheless the public transport is used by many citizens for both inner-city as intercity travelling, mostly resulting in negative perceptions because of the delays, high costs and a lack of flexibility.



Source: Harms et al. 2005

Using the ***bicycle*** as an alternative gives a feeling of independence, but 25% of the cyclists mention that the exposal to bad weather conditions is a problem. One fifth of the cyclists is annoyed by the behaviour of other people in traffic. Another problem which is attended by one fourth of the cyclist is the limited storage capacity in public spaces. The most profitable aspect of the bicycle are its modest purchase and usage costs, other aspects whereby the bicycle accelerated in comparison with other traffic means are the absence of delays and the feeling of independence it provides.

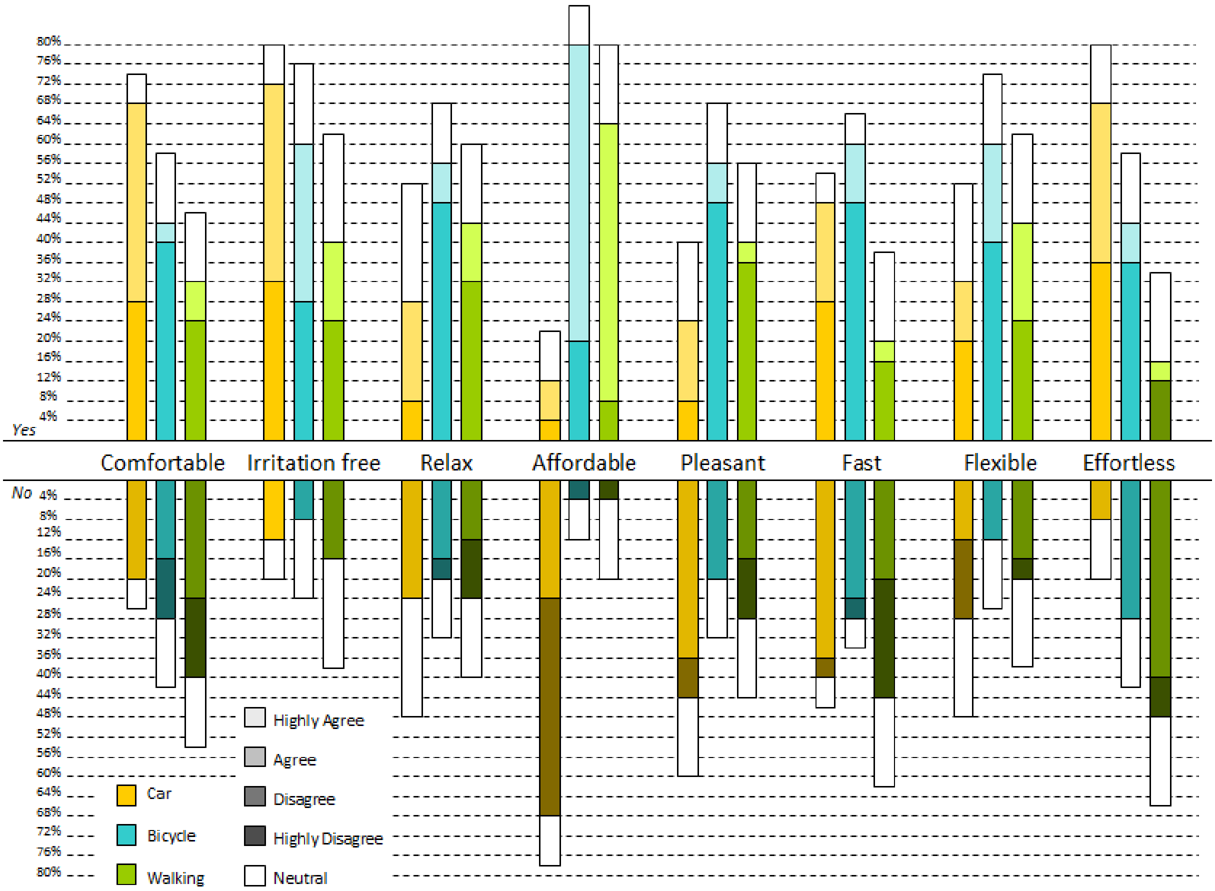
As regards emotions travelling by car and the bicycle show some similarities (see table above). Both transportation means are mainly associated with positive emotions. 52% of the Dutch population associates the car with joyfulness, and the bicycle even by 67%. Negative emotions are rare by both transportation means; only 6% of the Dutch associates the car with negative emotions, the bicycle is even less with only 4%. In contrast the public transport is only by 11% of the Dutch population experience as joyful. Therefore the public transport is mainly associated with negative emotions, one fifth of the Dutch even has feelings of aversion towards the public transport.

When taking a better look at ***experiencing mobility relevant to supermarket visits***, many equalities with the research of *Harms et al., 2005* can be found. They have investigated peoples perception onto 13 factors about home-work commuting, and a comparison between different transportation means (car, bicycle and public transport) has been made.

Because the different context of the transportation purpose, namely home-work commuting on hand and supermarket visiting on the other, Harms et al. do give an insight although their data is not applicable for the supermarket visiting situation. Therefore a questionnaire has been executed among 25 participants *[Appendix, I]* in order to understand more about peoples perception about 8 factors (comfortable, irritation free, relax, affordable, pleasant, fast, flexible and effortless) of home-supermarket transportation; so different ways of transport (car, bicycle and walking) could be compared. (Results are shown in the chart next page).

There are some similarities found between both researches of Harms et al. and the questionnaire about supermarket visiting. So even though the context of travel purpose is different (home-work and home-supermarket) people's perception onto factors like comfortable (car > bicycle), irritation free (car > bicycle), affordable (car < bicycle) and effortless (car > bicycle) is the same.

Differences do arise when comparing factors like: pleasant, fast and flexible. In the research of Harms et al. the car is more pleasant, faster and more flexible than the bicycle during home-work commuting. In the situation of home-supermarket visiting the bicycle is perceived as more pleasant, faster and more flexible. I would like to state that these factors may be influenced by the distance parameter. Home-work commuting has a longer distance range than supermarket visiting. It is likely that people see more advantages in a car for longer distances and more advantages in a bicycle for shorter distances.



From the questionnaire about supermarket visiting one could conclude that going by car is the most comfortable (68%) and effortless (68%), but least relax (28%), least affordable (12%), least pleasant (24%) and least flexible (32%) way of transport in this context. On the other hand going by bicycle is the most irritation free (72%), most relax (56%), most affordable (80%), most pleasant (56%), fastest (60%) and most flexible (60%) way of transport. Walking is the least irritation free (40%), least fast (20%) and least effortless (16%) way of visiting a supermarket. For more comparisons between the three different transportation modes, please take a look at the table above.

Conclusion

•According to Harms et al. the car is the most attractive traffic device for commuting because of its comfort, ease, independence, flexibility and also because of the speed and pleasure it provides. Most important disadvantages of car travel are: congestion, the costs involved and (aggressive) behaviour of others.

•In the context of supermarket visiting the bicycle is perceived as more pleasant, faster and more flexible than a car.

•The bicycle has much potential for supermarket visiting because it is perceived very positively; the bike can be made more competitive with a car when bringing solutions to the bicycles downsides (comfort, irritations and effort) in comparison with a car.

2.5. Sustainable mobility

Nowadays the consumer becomes more and more environmental conscious; people are aware of the environmental pollution caused by traffic. Therefore it is desired to make mobility more sustainable in the future. "Sustainable mobility" is a term that can mean different things to different people. The World Business Council for Sustainable Development defines "sustainable mobility" as "*the ability to meet the needs of society to move freely, gain access, communicate, trade, and establish relationships without sacrificing other essential human or ecological values today or in the future*" *[WBCSD,2001].* This definition emphasizes the social aspects of mobility. But for many people, the term "sustainable mobility" reflects more mundane concerns — concerns relating to whether the transportation systems on which our societies have come to depend can continue to function well enough to meet our future mobility needs.

"The vast majority of European citizens' lives in urban areas, and around 85% of the European Union's (EU's) Gross National Product is generated there. Sustainable urban mobility - allowing people and goods to move freely and safely while respecting the environment – is crucial both for our quality of life and for the health of the economy" [EC, 2007]. Yet most cities have invested most heavily in car-based physical transportation infrastructures and are now experiencing the most unsustainable levels of traffic and resource use. One of the consequences which cities with overbuilt roadways do face is the popularity of car usage, resulting to radical drops in public transport, walking and cycling.

Cities all over Europe face similar problems (congestion, road safety, security, pollution, climate change due to CO2 emissions etc.) and these problems are increasing constantly. *"Inaction would result in Europe having to pay an even higher price both in economic and environmental terms, as well as for the health and quality of life of European citizens" [EC, 2007]*.

The main environmental issues in towns and cities stem from the domination of oil as a transport fuel, which generates CO2, and air pollutant emissions. Air and noise pollution are increasingly worrying. *"Urban mobility accounts for 40% of all CO2 emissions of road transport and up to 70% of other pollutants from road transport, these have a negative impact on citizens' health" [EC, 2007]*. Therefore, sustainable transport policies may have their greatest impact at the city level.

"There is a need to create a new urban mobility culture in Europe. Citizens and decision makers have to think in terms of behavioural change. Only through a shift in mentality we can maintain our cities as attractive places to be and to go, and can ensure that they can continue to function as successful engines of the European economy" [EC, 2007].

"Options for making cities more environment-friendly include the development of clean, energy efficient transport technologies, as well as urban 'green zones' with features like pedestrianised areas, restricted access and speed limits. Energy-efficient driving and green procurement can also help to tackle this challenge" [EC, 2007].

"Alternatives to private car use, such as walking and cycling, collective transport or the use of the motorbike or scooter must be attractive and safe" [EC, 2007].

Conclusion

• It is desired to make mobility more sustainable in the future. *To do so; supermarket visits by bicycle should be encouraged.*

3. Market analysis

In this chapter the current mobility market will be explored. The existing products in the very diverse mobility market will be discussed; only some of the most remarkable will be described. Also some inspiring products which had less market potential will get mentioned. Later the discussed product will be valuated according the perceptual mapping technique, and the product characteristic will get compared. I want to finalise this chapter with a look into the future, and address the (potential) competitors for this project.

3.1. Existing products

The personal mobility market is very wide ranged, and diverse; moving from one place to another can be accomplished in many forms. Products in this market differ in functionality, character and complexity; therefore it might be useful to take a look at the existing product in current mobility market.

EMS E+ Mountain bike | Beixo SLIM | PUMA glow rider | ORMAZD | Helkama 101i

The ***bicycle*** is the one most reliable and ever lasting concept at the mobility market. The minimalist idea of using two wheels and a propulsion mechanism to drive can be seen as the archetype of the personal mobility concept. Nowadays bicycles use modern technology for styling and functional upgrades, like; electric hub motors, cardan drives, glow-in-the-dark coating and magnesium frames. In the Appendix some examples of bicycle innovations are shown (more specific information about the bicycles can also be found in the appendix *[Appendix, II]*).

Mobiky | Strida | Brompton | Giant | Dahon | Birdy | GoBike

The bicycle has evolved in appearance and functionality; one of the most successful added functionalities is making the bicycle compact and foldable. A ***folding bicycle*** is a type of bicycle that incorporates hinges or joints in the frame and handlebar stem that permit it to be broken down into a more compact size. As well, most folders have wheels of 20 inch (51 cm) diameter or less. Folding bikes can be taken onto public transport and into apartment buildings or workplaces where conventional bicycles are not allowed, facilitating mixed-mode commuting. In the pictures above some examples of the most remarkable folding bicycles are shown (for more specific information please take a look at the appendix *[Appendix, II]*)

In the short distance range (0-1km) some alternative mobility tools do exist. Those are specialised in, and mainly used to bring some (shopping) loads while walking. The advantage of these products is that they could be quite minimal and therefore relatively cheap. The disadvantage though is the fact that a user can only use it while walking.

Shopping carts | Ezcart | Pushcart | Plastic strolling baskets | Bucket cart

Supermarkets do invest in ***shopping carts, strollers and baskets*** for its visitors, making it as much comfortable and pleasant for the costumers as possible. In the pictures above, one can see some shopping tools which are mostly present inside supermarkets. There are various iron shopping carts and plastic shopping baskets. These items are property of the supermarket, and therefore may not be taken away from the supermarket terrain.

Strollers | Shopping scooter | Rollators | Suitcase strollers | Bag cart/stroller

For that reason people bring their own shopping device, as one can see in the row of pictures at the top of this page. These items are way smaller and cheaper. These strollers, rollators, scooters and carts are brought to the supermarket and are allowed inside when shopping items remain visible. The main function of these items is to carry the weight of the shopping, and not to move faster for instance.

Unicycle | SQRL | Scooby | PumGo scooter | Trikke | Pulse Kick 'N Go | Batavus Bike Stepper

Some personal mobility concepts seek their success in ***alternative gearing***, trying to introduce a fun element. The way of operating such a device is the main selling point, but those concepts should also be considered as functional transporters.

E-bike | E-Bikeboard | Toyota Winglet | Segway | Yamaha Bobby

A new phenomenon in the personal mobility market is the attendance of ***electric powered*** vehicles. The technological development of compact battery packs on one hand and electronic speed chargers on the other made it possible to create vehicles with a relative big action radius.

Taga | TrioBike | Gazelle Cabby | Babboe Big | Zigo

The ***carrier cycle*** is a human powered vehicle concept known from the past, designed and constructed specifically for transporting large loads. Still there is a need to for transporting large loads, but in current mobility market the design of the cargo bike is revised and let to some evolved varieties. The design nowadays is more dedicated to the purpose the vehicle has to execute. This resulted in the appearance of carrier cycles, 'specialised' in the transport of children or shopping. Those cargo vehicle designs usually include a cargo handling area consisting of a steel tube carrier, an open or enclosed box (cabinet), a flat platform, or a wire bracket basket. These are usually mounted over one or both wheels, low behind the front wheel, or between parallel wheels at either the front or rear of the vehicle. The frame must be constructed to handle loads several times that of an ordinary bicycle. Other specific design considerations include operator visibility and load suspension.

3.2. Inspiring products

Bamboo bike | Spring bike | Itera plastic bike | Innervision IV-1 | Cardboard bike

Beside the yet existing products there are also some inspiring products which were or are less commercially successful. Those concepts are mainly inspirators because of the new material applications which were used from both ecological and economical perspective as you can see in the pictures above. For more specific information please take a look at the appendix *[Appendix III, Details of inspiring products]*.

Piaggio MP3 | Mitka | Roodrunner

New concepts arise when ***multiple functionalities*** from different existing vehicles are combined, or the disadvantaged in current concept are tried to be eliminated. The biggest disadvantage of cycles and scooters for instance is the fact that users are exposed to bad weather conditions. This problem is eliminated by the following two concepts; Piaggio MP3 and Mitka, trying to combine functionalities from both automotive and cyclist worlds. Also the Roodrunner has some remarkable properties, which are inspired by a car; a big trunk and steering system for instance.

The following category of inspiring products, consisting of prototypes and renderings found on the Internet. These concepts have very ***interesting product layouts***, and are mostly applicable for this project. The vehicles are quite small, and most of the time foldable. Beside that they also have a carrier cabinet, in which one can store some belongings.

Suitcase-bike1 | Everglide | Canguro | Suitcase-bike2 | D-carry | cooler-scooter | Luggage scooter

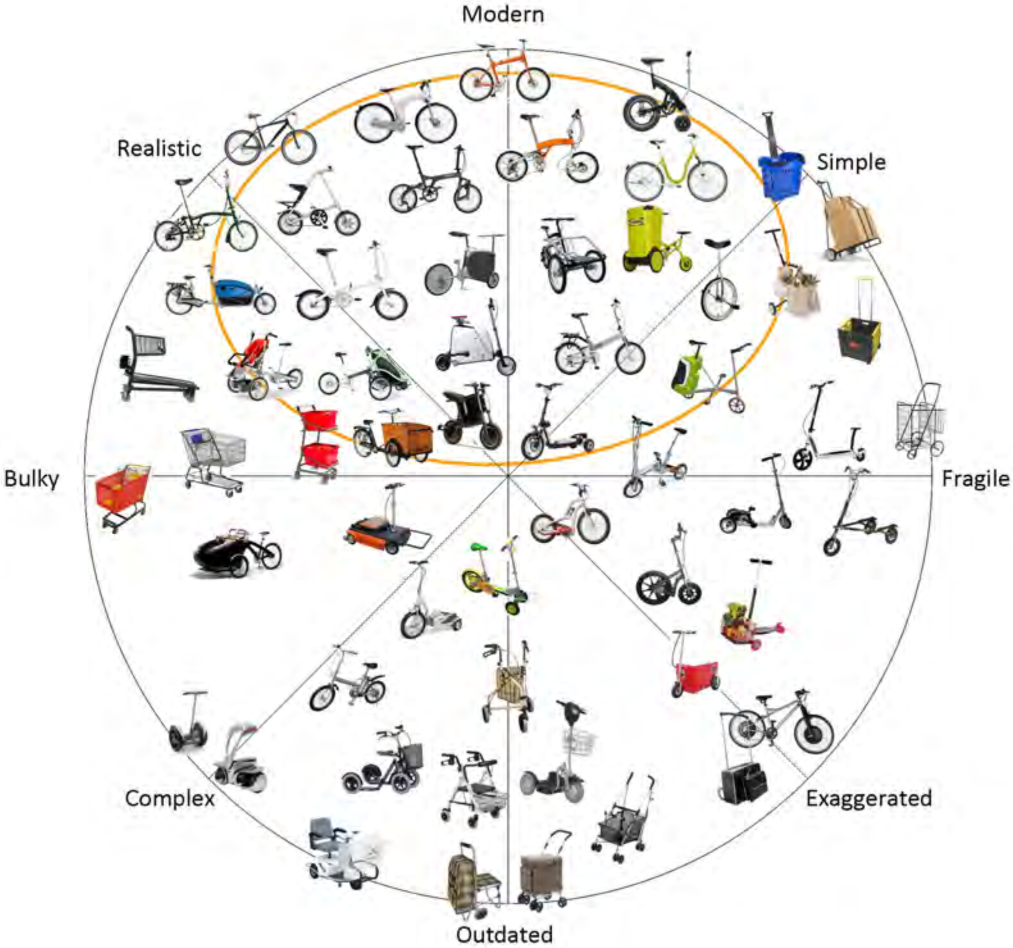
In the above pictures two suitcase-bikes are displayed; the suitcase functions as a frame in which the wheels can be housed when folding. The Everglide and Canguro are also a fusion between bicycle and cabinet, although in these concepts the cabinet is used for carrying purposes. The D-carry is also a mini carrier bike, but in this concept the carrier cabinet (a normal shopping stroller) can be detached. The cooler- and Luggage scooter are electric powered vehicles meant to transport some cold drinks or luggage.

3.3. Perceptual mapping

All discussed existing products do have certain product characteristic; how potential consumer perceive those characteristic might be interesting. User perception is an important issue in product design. However, as the variety of products on the market increases, it becomes more difficult to determine user perceptions. *"To study the perceptions of products by target consumers, perceptual maps are often used by marketing researchers, psychologists, and designers as a means for visualizing consumer perceptions of product alternatives on the market" [Urban & Hauser, 1993; Moore & Pessemier, 1993].*

A perceptual map of some product semantics will be made to be able to evaluate the found products on the mobility market. Each alternative product is represented by a photograph that has been pre-processed: remove the background and other irrelevant details. To reduce the number of stimuli, a set of representative stimuli are selected; this is already done while discussing most diverse existing product alternatives in paragraph 3.1 and 3.2.

I use the perceptual mapping method to evaluate the value of the found products in terms of semantics like; modern – outdated, complex – simple, fragile – bulky and exaggerated – realistic. The mentioned semantics are contrary couples; between the opposites there is an axis that explains the value of the product on that specific semantic.



My perception is that products like the Segway and the Toyota Winglet are way to complex in the context of supermarket visiting; they are hard to produce and to understand from a user perspective. Because of the complexity it might take a while for the potential user to get to trust the product, one does not know how the product reacts on user input. In contrast strollers and baskets are very simple to produce and use, everyone knows how they work and react on user input.

But many strollers and carts are very outdated, as one can see at the diagram above. Strollers, carts and rollators are mainly products for the elderly resulting in a negative product image. Modern and innovative products on the other hand, like the PUMA glow rider, Helkama 101i, Birdy and SQRL show new features, drawing more positive attention.

I believe products must look realistic, providing a real solution to a serious problem. Strida, Brompton and Beixo are very realistic, just focussing on providing reliable tools to consumers with specific needs. But there are also products onto the mobility market, which are not realistic at all. Like a cool-box bike for instance, this product is more a fun item and is quite exaggerated. Products can be exaggerated in functionality like a 750 Watts electric assist in a mountain bike, but also in price like the HENK suitcase which is extremely expensive.

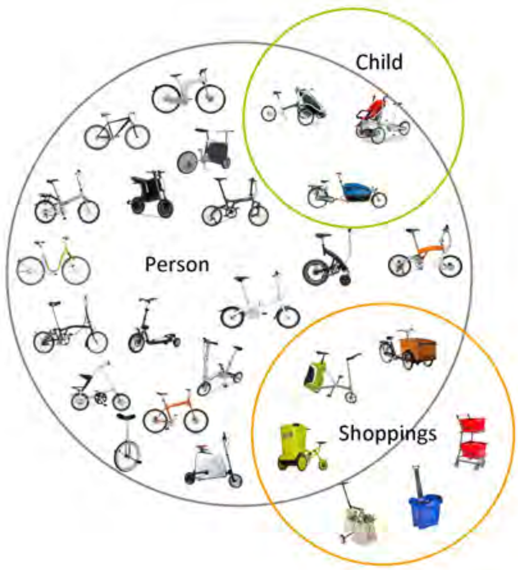
In appearance some products may seem to be very bulky, they are way to big or heavily build to perform their task. On the other hand some other products look very fragile, making it hard for potential users to trust the product on its quality and reliability. For example I believe the Trikke Roadster and the Pulse Kick 'N Go are to fragile in appearance, I might be worrying if the frame brakes when I ride it.

I am positive (orange area) about products that are realistic, modern and simple. The design space of this project: “Stand-by Mobility Device for Local Purposes” can be market by the products displayed in the orange area. The outcome of this project will fit in between those displayed product in terms of functionality, style, size, price and product layout.

3.4. Product characteristics

Beside the perception of product semantics products can be compared and evaluated according the product characteristics. The “Stand-by Mobility Device for Local Purposes” should be competitive with a bicycle in terms of price and weight. The strategy behind this thought is that potential users will decide whether they want to purchase the new concept or a ‘normal’ bike. In the pictures below the price and weight of the earlier found existing vehicles from paragraph 3.1 and inspiring product from paragraph 3.2 are displayed; both in a price and weight diagram. Only the products which were selected by the perceptual mapping method are used, those were the most relevant items standing in the orange area. It is most likely that a potential consumer will spent approximately 700 Euro maximum to purchase a shopping vehicle which may weight 16 kilogram maximum.

In the short distance mobility range, diversity in product functionalities is discovered. Most of the product mainly focus on the transportation of one single person (grey circle), but others are more dedicated to perform a specific task. While moving; one could bring shoppings (orange circle), or a child (green circle) along. Those categories are divided into two sections; one which only displays the dedicated purpose of that single product, and the other which displays the ability to perform the specific task plus the ability to transport a person as well. In usage the dedicated tasks of bringing shoppings or a child are competitive with the functionality of a car. The products displayed in the circular diagram are some of the alternatives, in terms of task performance, for a car. The idea behind the “Stand-by Mobility Device for Local Purposes” is that it is competitive with the car in usage, therefore it should encourage users to execute task with it, normally done with the car.



3.5. Future products

On the Internet many futuristic mobility concepts can be found. Most of them are made by brands in the automotive industry. They use these concepts to explore future possibilities; new chances may rise from these studies one had never thought of before. Many of the futuristic concepts show alternatives to the car. The vehicle becomes more personal, smaller and flexible in usage. The concept displayed below will be used as inspiration in product appearance, functionalities and will encourage to come up with something totally new.

Yamaha Deus

Nissan OneOne

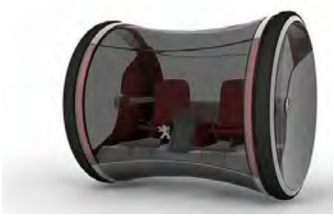
Audi Snook

Volswagen One

BMW Wahnsinn

Noah Unicycle

Segway Centaur



Renault Ozone

3.6. (Potential) competitors

This search for (potential) competitors provides both an offensive and defensive strategic context through which to identify opportunities and threats. From the market research to existing products one could see that all kind of brands are able to position a new vehicle onto the mobility market. In this paragraph the level of competition with the “Stand-by Mobility Device for Local Purposes” project will be discussed in which either knowledge institutes and/or lifestyle, sports, automotive, cycle and even other brands do participate.

In the diagram below some of those competing brand are displayed within a certain level op competition. From the search to similar products like the “Stand-by Mobility Device for Local Purposes” one can conclude that this very project is unique (orange circle only contains this project, there is nothing found to be alike) because of its intent to be intuitive and multi-functional in usage. This will become clear when addressing the following levels of competition:

First Level: Devices adaptable in configuration to execute some dedicated tasks; carrier, stroller/pram and cycle. The biggest selling point is the multi-functionality of the product. There are carrier cycles which can be transformed into prams, with the spare parts one can create a bicycle as well. These products are competitive in functions but not on a usage level. The products in this level are missing the intuitive use, where all needed parts are always present. The brands in this level of competition can be most dangerous for this project when applying an intuitive usage and when reducing the size of their products.

Second level: Traction devices with added functionalities; foldable, electric, (fun) alternative gearing. These brands have developed an expertise in certain functionalities. When applying multiple of these functions those companies could come up with the same product idea, and create a "Stand-by Mobility Device for Local Purposes" as well. These mainly bicycle brands, provide many solutions that are competing in terms of performing certain tasks.

Third Level: Alternative mobility, dedicated to lifestyle, children and longer distances. Competing more in knowledge and monetary terms, rather than pure functional. These automotive brands can use their reputation to penetrate the short distance mobility market. Lifestyle and sports brands can do the same on behalf of marketing strategy; although they are not designing or producing the products, they can use their brand image for selling purposes. Brands known from child-related products can decide to implement traction devices compatible with their existing product range, and so increase independence from bicycle industry.

Beside the many threats discussed in the levels of competition, there are also many opportunities for this project to become a participant within that very similar field of action. The introduction of a highly protective baby carrier onto a cycle concept for instance, may result in gathering parts of market share from both Batavus and Maxi-Cosi. This because a consumer does not need the separate Batavus bike and Maxi-Cosi baby carrier anymore. One can also decide to start an alliance with Maxi-Cosi and create a bicycle with baby carrier adapter to compete against Quinny and Bugaboo which are direct competitors of Maxi-Cosi. The created multi-functional concept may also become competitive with the bicycle brands.

4. Consumer analysis

In this chapter the focus is on the consumer. While doing a segmentation study, and describe some consumers scenario's I try to discover the consumer's behaviour and their underlying needs. This will help to gain insight into consumer perspective; with this very insight a target group can be set.

4.1. Segmentation

In order to get better insight into the different types of consumers in the mobility market in North-America and Europe, a segmentation study will be conducted. These continents do have most potential for a short distance mobility device because of the high urbanisation rates. In North-America 82% and in Europe 70% of the population lives in urbanised area's. This means that distances to facilities are limited, and the acceptance of a short distance device implementation is more likely than in rural area's.

In the Western World people are used to live in cities for decades; this has led to the concentration of activities in the cities. The bigger companies, universities, warehouses, etc. are mainly settled in the bigger cities. Because of this cities do attract people from the region to work, educate themselves and shop for instance, leading to a huge amount of traffic activities.

The diversity of people and their activities can be explained as the existence of different market segments. Consumers from different market segments do have different characteristics and therefore different preferences and needs. The living situation; type of house, type of household and household income are some of the characteristics that have an influence on determining the segments. Personal characteristics like; education level, gender, ability, and age also help to define the personal preferences and needs of potential consumers.

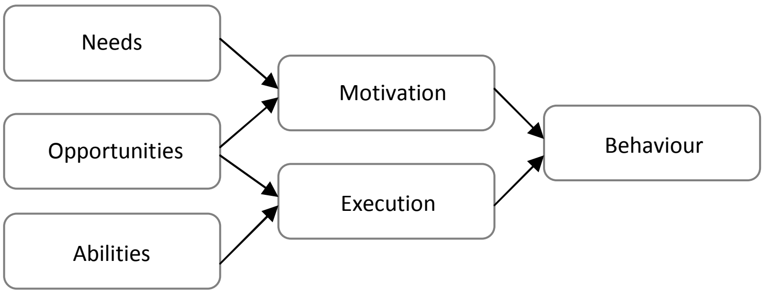
4.2. Scenarios (persona)

To enrich the insight in the potential success of a "Stand-by Mobility Device for Local Purposes" implementation in different market segments, four scenarios will be made. The scenarios describe the way certain people live, their mobility needs and the ability they have to perform certain mobility related tasks. The four scenario's will not describe total urban live, but will discuss four most diverse, and characteristic lifestyles. Namely; 1) Business couple, 2) Family with kids, 3) Students/Young couple and 4) Elderly. These personas are described in detail at the appendix [Appendix IV, Scenarios (persona)].

4.3. Consumer behaviour

Consumer behaviour attempts to understand the buyer decision making process, both individually and in groups. It studies characteristics of individual consumers such as demographics, psychographics, and behavioural variables in an attempt to understand people's wants. It also tries to assess influences on the consumer from groups such as family, friends, reference groups, and society in general. Consumer behaviour can be defined as *"the process and activities people engage in when searching for, selecting, purchasing, using, evaluating, and disposing of products and services so as to satisfy their needs and desires"* [Belch, 2004].

Being mobile at most profitable way requires proper decision making, because in every situation people can choose between several available transportation means. At first consumers will recognise a specific problem relevant to mobility and later they will search for a solution to that problem. The problem originates from the desire of being mobile, and so people will compare a kind of transportation means to come up with the one most profitable suiting their needs and abilities.



The above standing NOA-model (Needs, Opportunities and Abilities) explains the consumer decision making process. As mentioned before people do have the need of being mobile for many purposes. For instance if someone wants to go to the supermarket 3km away from home one needs to move. If there is a bicycle or car available one has two opportunities to move over that specific distance. The needs and opportunities do define the motivation; why and how one can move. Although the consumer has to possess a set of abilities to make it possible to move, in this case one has to have a drivers licence or be able to cycle. The presence of the transportation device and the ability to drive it defines the way of execution. Both motivation and execution have influence onto the final consumer behaviour, as one could see from the above standing diagram.

From the NOA-model one can see that when behavioural change is requested to reduce congestion and environmental pollution for instance both the motivation and feasibility should be influenced. This project can have an influence on the abilities it provides to people, due to the introduction of new ***benefits*** for people with mobility needs.

4.4. Consumer storyboard

In order to discover people's behaviour relevant to supermarket visiting, a storyboard has been made as you can see in the appendix *[Appendix V, Consumer storyboard]*. Supermarkets in three different cities (Rotterdam, Delft and The Hague) were 'investigated'. Visitors were observed and pictures of their behaviour were made. (Because of supermarket policies I often was not allowed to take any pictures). In addition there have been numerous conversations between observer and visitors; this due to understand the problems, difficulties and annoyances of supermarket visitors in relation with home-supermarket transportation.

Most remarkable findings:
- People bring their own shopping equipment, resulting in combinations of personal and supermarket tools.
- There are many 'granny' trolleys parked at the service desk.
- Mothers very often use their baby pram as a substitute for a shopping cart.
- One of the reasons why elderly use a shopping cart is the stability it provides while walking.
- Visitors who are by car or bicycle have to bag their shoppings and carry their shoppings in order to reach their transportation mean.
- Carrier/cargo cycles and kid trailers can not be parked properly.
- Sometimes doorways are slit in half, because shopping carts may not be taken outside. Disabled and mothers with prams had to entre and leave trough the emergency door.

4.5. Consumer needs

*People desire mobility. They desire it both for its own sake and because it enables them to overcome the distance that separates their homes from the places where they **work, shop, seek medical attention, go to school, do business, or visit friends and relatives**. [WBCSD,2001].* In paragraph 4.1. about segmentation, I explained why the "Stand-by Mobility Device for Local Purposes" has most potential in the European and North-American market. Although there are cultural differences and other rules of engagement the consumer needs are not that much different. This can best be explained in a set of pictures, there are many similarities as showed below.

On the move in New York

On the move in Amsterdam

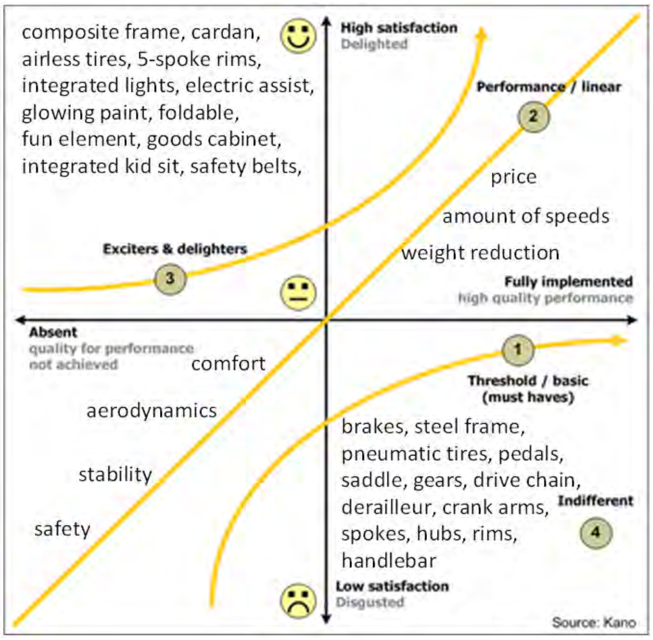
Society is changing, and is expecting more ***intelligent*** and ***affordable*** mobility solutions. Citizens also expect ***seamless*** and ***accessible*** collective transport and ***safe*** infrastructure for walking, cycling and private vehicle use. They expect more ***flexible*** transport solutions for both freight and passenger mobility.

In order to perform various daily tasks people must drive a car, walk, use bicycles or two-wheeled motorized vehicles, or rely on various forms of public transport. Bicycles are limited in their range and in the amount of weight they can carry. Two-wheeled motorized vehicles are less limited in both these regards, but are quite expensive. Public transport is generally less expensive in terms of the daily financial outlay required to use it but is often difficult to reach and provides relatively poor and inflexible service. The car is the most expensive option and is getting less efficient in the city because of congestion.

*"The challenge is to make urban transport more accessible for all. Society expects mobility solutions that are **flexible**, **affordable** and **comfortable**. Citizens want **seamless, safe** and **efficient** transport both for freight and passengers" [EC, 2007].*

Increasing access to flexible, affordable means of mobility can be achieved through improvements in any or all of the following dimensions: 1) Reducing the cost of various types of motorized vehicles, 2) Improving the flexibility and reach of public transport systems, 3) Developing new transportation devices that combine flexibility with low cost is a third.

4.6. Consumer satisfaction



Now, a better insight is gained into product characteristics and consumer needs, it is time to link both to each other. To do this the Kano diagram will be used; this model offers some insight into the product attributes which are perceived to be important to customers. Kano's model focuses on differentiating product features, as opposed to focusing initially on customer needs. Kano also produced a methodology for mapping consumer responses to questionnaires onto his model.

The diagram contains a pair of axis labelled performance-X and satisfaction-Y. It contains three plotted lines; 1) Basic, 2) Performance and 3) Exciters. The line about the basics (must haves) explains that no matter how good the achievement, it isn't going to impress the customer. The customer expects this, without achieving this you aren't even in the market. The performance line show that the more of this feature, the happier the customer is. This keeps you in the marketplace. The line about exciters shows the effect of product features consumer did not expect. The customer is pleasantly surprised, even if the actual achievement is not very good.

Relevant to mobility devices this means that users expect brakes, steel frame, pneumatic tires, etc. for example as you can see in the diagram. If those are absent people will be disgusted, and even when present people will only feel neutral because they expected to be part of the design. When looking at the performance characteristics like stability, comfort and weight reduction for instance people will feel more delighted, the better they done. Unexpected product features like composite frame, cardan and 5-spoke rims will get people excited, making them choose one product over another.

4.7. Target group

The target group will be set by means of the consumer needs relevant to mobility. The focus is on a mobility device as an attribute for shopping (carrying) purposes. In more or inferior degree all people have to deal with this, but the ones that are most representing are the people living in highly urbanised areas, and do not have a car. Dependent on the household situation and their activities the "Stand-by Mobility Device for Local Purposes" could function as a substitute for a car. These people are between 20-40 years old and do like to live in strongly urbanised area's because of the many activities present. It is most common for them to rent a city apartment, or to buy a house in or near the city centre. These people are commuters, travelling every day from and to their jobs. The couples in this target group are most of the time double-income household; working full-time both, or one of them may be working part-time.

In bullet points the following characters come up:
• Singles and Couples
• Living inside the city centre
• Commuters and shoppers
• 20-40 years old
• Dynamic lives
• No car

In the following table a calculation (estimation) about the target group size in the Netherlands has been made. The data is gathered from CBS (Central Bureau of Statistics) and with some factors from a Dutch supermarket firm it was possible to make this estimation. (You have to read the table from top to bottom, factors will 'filter' out categories inside the total target group)

<table>
<tr><th colspan="6">Estimation of target group size in the Netherlands, 2008</th></tr>
<tr><td colspan="6">16.405.399 inhabitants</td></tr>
<tr><td colspan="6">7.242.202 households</td></tr>
<tr><td colspan="3">19% very urban areas (>2500 houses/km2)
1.376.018 households</td><td colspan="3">24% high urban areas (1500-2500 houses/km2)
1.738.128 households</td></tr>
<tr><td colspan="3">98,2% 0-1 km distance to supermarket
1.351.249 households</td><td colspan="3">92,8% 0-1 km distance to supermarket
1.612.983 households</td></tr>
<tr><td>60% singles
810.749 households</td><td>25% couples
337.812 households</td><td>15% families
202.687 households</td><td>45% singles
725.842 households</td><td>30% couples
483.895 households</td><td>25% families
403.246 households</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="2">43,5% Single and no car
668.417 households</td><td colspan="2">11,2% Couples and no car
92.031 households</td><td colspan="2">5,2% Families and no car
31.509 households</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="6">Target group size
791.957 households = 11% of the Dutch households</td></tr>
<tr><td colspan="2">singles in urban areas with no car
84,4% of target group</td><td colspan="2">couples in urban areas with no car
11,6% of target group</td><td colspan="2">Families in urban areas with no car
4,0% of target group</td></tr>
</table>

In this above standing table one can see the amount of Dutch inhabitants and the amount of households in the Netherlands. 43% in total is living at highly urbanised areas; these household are divided into three household types (singles, couples and families) and the amount of these households living at a 0-1 kilometre distance from a supermarket is calculated. In the end the total target groups size is represented by 791.957 household; existing of 84,4% singles, 11,6% couples and 4,0% families.

5. Conclusion analysis

• Because of congestion car usage in urban areas becomes less efficient
• Nevertheless the car is the most attractive traffic device because of its comfort, ease and speed.
• Urban mobility can be made more sustainable by using alternatives like cycles more instead.
• People experience the bicycle as very pleasant, and is appreciated because of it reliability (in travel time) and affordability.
• From a market perspective it should be possible to introduce new functions in cycling to make it more competitive with a car during usage.
• In purchase the concept should be competitive with a bicycle's price and weight.
• In usage the concept will be competitive with the car, therefore it should encourage users to execute task with it, they normally use the car for.
•A mobility device which is independent from car parking spots and bicycle racks might be profitable for supermarket visitors.
•There is enough space inside the supermarket's shopping paths to take such a mobility device along inside the supermarket (assuming that the dimensions of the device are smaller than an average shopping cart).
•Car and bicycle visitors travel over comparable distances, but with a car one can bring more shoppings. Cycling to the supermarket might be more attractive to consumers when it is possible to bring more shoppings back home.
• People who are walking to a supermarket travel over shorter distances and bring less shoppings back home; enabling walking visitors to bring more shoppings, with less effort, might be profitable for consumers.
•The bicycle has much potential for supermarket visiting because it is perceived very positively; the bike can be made more competitive with a car when eliminating the downsides of the bicycle (discomfort, irritations and effort) in comparison with a car.
• The concept's design will focus on being simple, modern and realistic.
• (Potential) competitors are knowledge institutes and/or lifestyle-, sports-, automotive-, cycle- and even other brands.
• People need mobility devices for a lot of (mainly local) purposes; working, shopping, education and visiting for instance.
• The concept can have an influence on consumer behaviour by giving input to people's abilities, due to the benefits the concept provides in comparison with other mobility alternatives.
• Customers do expect the device to have the basic product features which make them only feel neutral, they feel happier the better the performance features are, and unexpected features will get people exited, making them choose one product over another.
• The focus is on a mobility device as an attribute for shopping (carrying) purposes. In more or inferior degree all people have to deal with this, but the ones that are most representing are the ones living in highly urbanised area's without a car.

6. Design Criteria

6.1. Norms

The following norm could be relevant for the “Stand-by Mobility Device for Local Purposes” design project:

1) **NEN-EN 14764:2006** *Urban and en racing bicycles - Safety requirements and test methods*
2) **ISO 11243:1994** *Cycles - Luggage carriers for bicycles - Concepts, classification and testing*
3) **ISO 4210:1996** *Cycles - Safety requirements for bicycles*

6.2. Demands

Usage

• The design has to be a wheel based mobility device which enables people to move, while making use of the infrastructure of bicycle lanes and pedestrian area’s.
• The device has to provide the ability to switch modes and make use of three different configurations (riding, walking and stand-by).
• The device has to enable people to carrying some shoppings in a comfortable way.
• Users between ages of 14-65 years should be able to operate the device.
• The device should have a parking position, avoiding it to roll away.
• The seating height needs to be adjustable.
• The steering height needs to be adjustable
• Shoppings have to remain visible inside the supermarket.
• The turning radius of the walking mode should be substantially smaller (1-1,5m) in comparison with the riding mode (4-5m) in order to take narrow turns in the supermarket.
• The vehicle in walking mode must be able to make a u-turn (180˚) in a 2m wide shopping path without lifting the device of the ground.
• When folded the wheels of the device should still be able to roll, in order to transport the device over the floor, stair steps, etc.

Dimensions

• The device should be able to pass trough a door opening of 80cm wide.
• The maximum width of the device when folded is 40cm (half a door opening).
• The required floor space of the folded device may not exceed 80cm x 40cm.
• The device should be easy to manoeuvre because of the small spaces and obstructions within crowded inner city usage; therefore the maximum width in riding and walking mode is 70cm.
• The wheel size is set to a minimum of 14inch (scooter wheel) and a maximum of 20inch (folding bicycle wheel). This regarding comfort and road contact resistance.
• At least one wheel should fit within a bicycle rack in order to lock it.
• The tires should be thicker than the metro rail gap, so it would not get stuck within it.

Safety

• Moving parts that are within reach of the user has to be covered firmly.
• The device must have a reliable breaking system at the rear wheel at least.
• The vehicle must have a red rear reflector, white reflectors at the wheels and four yellow reflectors at the pedals.
• The vehicle must have a head light when riding in the dark that produces white light and a red rear light.

Loads

• The device’s construction should be able to hold the 102kg (body weight P95 Dutch male 20-40 years) as a maximum bodyweight of the user and an additional 15kg of shoppings, resulting in a total load of 117kg.
• The device has a maximum weight of 20 kg; because people have to be able to carry the device up and downstairs.

Stability
• The device should be stable at all times, wheels onto the ground permanently or use a bicycle stand.
• The transported good have to remain horizontal within a 5 degree margin at all times, and may not fall off.

Sustainability
• The device has to be emission free.
• Materials that are relatively easy to re-cycle have to be selected.

Legislation
• The user should be able to see the ground for at least 10 meter in front. (Brommerwetgeving)
• The device has to meet the requirements as set in the Dutch traffic laws (Nederlandse verkeerswetgeving).
• The maximum width of two wheeled bicycles is 0,75m (this requirement is used although the concept may have more wheels).
• An electric power assistance may only be 250 Watts maximum.

Price
• The device's maximum fabrication cost price is 300 Euro.

6.3. Wishes

• The device will stimulate the combination of both indoor and outdoor usage
• The device limits the time spent onto preparing activities before the actual usage to several seconds instead of minutes.
• Parts that get worn out should be easily replaced.
• The assembling time must be as less as possible, therefore also the amount of parts should be as less as possible.
• In disposal parts should be easily separated, and parts should have a material label in order to stimulate recycling.
• The load of shoppings is set to 7,5kg but it is desired to increase this to a 15kg maximum.
• The device should be as light weighted as possible, taking 16kg as a target.
• It is desired to make use of pre-fabricated parts as much as possible.
• The device must have a breaking system at the rear wheel, but it is desired to implement brakes at the two front wheels too.
• It is desired to design the vehicle in such a way very little maintenance is needed.
• Greasy parts are avoided as much as possible, or lubricated parts are desired to be shielded in order to prevent contact with the user.
• The device is desired to fit within a car's trunk.
• The point of gravity must be as low as possible, in order to increase stability as much as possible.
• The cost of ownership is desired to be as low as possible.
• The device's selling price is desired to be 700 Euro approximately.

7. Vision

The mobility market is growing, and shows the upcoming of new products in the appearance of innovative tricycles, kick scooters, foldable bicycles, strollers, etc. More and more 'dedicated products' are launched onto the mobility market, which are strongly connected onto some specific purposes, and therefore can be more effective in its use. The "Stand-by Mobility Device for Local Purposes" (SMDLP) project aims to respond onto this marketing trend. The introduction of a fusion between a folding cycle and a carrier cycle shows great opportunities for supermarket visiting purposes. I believe there are many people willing to do their shoppings with such a dedicated shopping device when it makes supermarket visiting easier, faster and more comfortable.

Urban mobility can be made more sustainable by using alternatives like cycles more instead of the car. The SMDLP will be a human powered vehicle, trying to be the more environmental friendly alternative while being the true solution on urban congestion. Therefore people who are living in highly urbanised areas have to be stimulated to use the SMDLP instead of alternatives like the car. I believe this can be achieved by introducing new functions into cycling that are competing with the car's functionality.

I believe the SMDLP could be best designed at a design studio in corporation with a bicycle company. In this way the design studio can focus on the new functionalities and working principals while making use of the knowledge of the bicycle company. The device can be made by the bicycle manufacturer, making use of many yet existing bicycle parts, and with use of the current distribution lines of the bicycle company directly sold to the end user. I believe when the bicycle company is willing to produce the vehicle for a competing price (leading to low cost of ownership) many potential end user are willing to buy the SMDLP when the price is comparable with a 'normal' bicycle's price. In the end such a device could be beneficial to all; people – profit – planet.

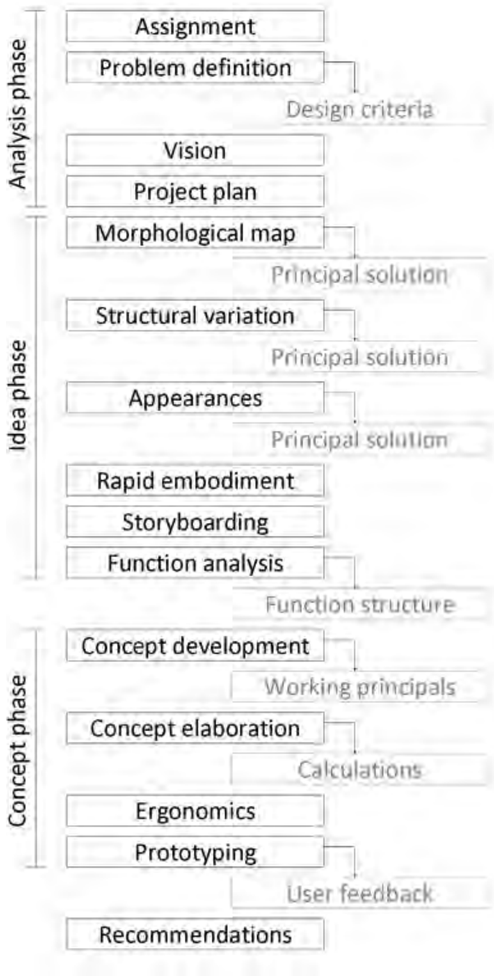
In this design process the focus is on functionality and a well operating device should be delivered for a competing price. Therefore material selection and production methods should be as low budget as possible. People will eject the SMDLP when the price is too high or when it does not function very well. Therefore I believe it is more important to focus on working principals and cost price reduction instead of the aesthetics of the device.

The SMDLP intents to be the alternative for urban mobility: the device is an attribute 'dedicated' to supermarket visiting. People living in highly urbanised areas could use the SMDLP to transport (over short distances of 0-1km) themselves to the supermarket, gather shoppings (average is 7,5 kg and max 15kg) inside the supermarket with it, cycle back home and take the SMDLP along inside when storing the shoppings in the fridge or closets. The SMDLP can be folded into a compact package so people are able to store the device itself; 'stand-by' in the hallway, balcony or any room. I believe connecting both indoor and outdoor usage, makes supermarket visiting way easier and faster, and may be an innovation in urban mobility.

8. Project (design) plan

In order to be able to write a project plan, it is important to know what is expected to be accomplished in this (design) phase. In the first (analysis) phase, most of the required information about the subject is gathered as described previously. With that information it is now possible to create a 'Vision' and use systematic design methods like a 'Morphological map' and 'Structural variation' to generate ideas. Those ideas are in the first place principal solutions, and after further elaboration they become concepts. To gain better insight in predicted user interaction with a design, 'Storyboarding' might be a powerful tool. These above described methods will lead to a systematic design approach. After all, in this second (idea) phase a proper idea generation and in the third (concept) phase a thorough concept development, user feedback and a finalized concept is expected.

This design process requires a subdivision in problem solving; depending on what kind of problem arises different methods will be used. In all these subdivisions choices will be made; the combination of choices made during these phases form the final concept. The approach chart underneath is correlated with a product development strategy which I will explain after the chart.



First of all my 'Vision' provides a direction in which to design a new concept. I explained what I would like to do and how this solution can be relevant for the target group. Within this 'Project Plan' I would define the strategy I will use to come to a new and innovative concept. The strategy which will be used is the "Divide – Solve – Reconnect" strategy. This strategy first divides the problem into sub-problems, which have to be solved and after that the solutions will be reconnected to each other. To be able to do so, a 'Problem definition' was made. Here I will address the main problems and divide them into sub-problems ("Divide"- Phase). In this phase it will come clear which subjects are in conflict with each other; this forms a problem. After the problems are made clear, decisions should be made on hand of the relevant 'Design criteria'. These criteria provide guidelines which define the direction I like to go when developing such a product.

When designing a technical product it can be very handy to know which functions are included. I will structure the technical functions of the product according the 'Function analysis' method. Organising the functions can be a very powerful tool to generate new working principals. Now it is clear what the product is supposed to do, it is time to apply these principals. In the first phases the solutions are very 'abstract' or 'ill-defined', which are called 'Ideas'. The design is not very clear and there are many 'black-boxes'; so the product does not really function well, but is a solution in principal. To come to these ideas I will use the methods of 'Morphology', 'Principal solutions' and 'Structural variations'. ("Abstract, Solve"-Phase).

After collecting information that helps to come to a solution, the product will get developed more and more into the 'concrete'. Methods such as: 'Product style studies', 'Ergonomic detailing', 'Construction detailing' and 'Production detailing' will be applied in the 'Concept elaboration'. This is the "Abstract – Concrete" strategy. The so called 'elaboration' of the concept should bring solutions to all the problems, based on the choices made. ("Concrete, Solve"-Phase).

After this concept phase, an evaluation should take place to see if the concept does fit to the user needs. Users are testing the concept, with help of 'Prototyping', and probably will provide alternatives, or at least explain what they like or dislike about the product. This is called 'User Feedback'.

With this new input the concept should be reviewed and adjustments can be made in this 'elaboration' of the concept. All problems should be solved and get combined into to final concept. ("Reconnect"-Phase). The design process will be finalised with some 'Recommendations' in order to improve the concept in the future.

9. Morphological map

Before creating solutions for the design problem a morphological map was made partly from the earlier found ‘reference products’. From the chapters about existing and inspiring products in particular, an overview of the used components inside those products was made as an inspiration. Mapping those components will result in a clear overview of sub-solutions. Later on in the process the morphological map can be used for making new combinations.

The “Stand-by Mobility Device for Local Purposes” will consist out of different parameters, like a frame, gears, wheels etc. etc. With this morphological map I will try to find all kind of possible solutions to the defined problem as described in the problem definition of this project. From each category of parameters component will be selected and linked onto each other in order to generate ideas. For example a Tricycle + X-shape frame + chain drive + luggage at front + climb wheel + pedalling + folding crate = a possible solution.

Wheel Layout	 Bicycle	 Tricycle	 Quadricycle		
Frame Layout	 Double triangles	 A-shape	 Parallelogram	 X-shape	 Jointed arc
Gears	 Chain drive	 Cardan drive	 Planetary gears	 Belt drive	
Luggage Position	 At front	 Under seat	 At the back	 In frame	
Stair Climbing	 3wheel	 Climb wheel	 Stair dragging	 Carrying	
Power input	 Pedalling	 Stepping	 Kicking		
Luggage carrier	 Basket	 Trolley	 Canvas bag	 Folding crate	 Shopping cart

In practice above standing morphological map was used as a tool during generating ideas. I looked at elements which are essential for all possible solutions (parameters), later for each identified element theoretical solutions were realized (components). In other words; generating ideas is a process of systematic combining sub-problems and their coherent sub-solutions. In the following chapter about "Idea generation" the results are displayed.

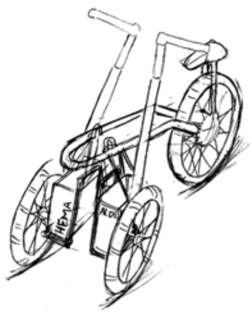
10. Idea generation

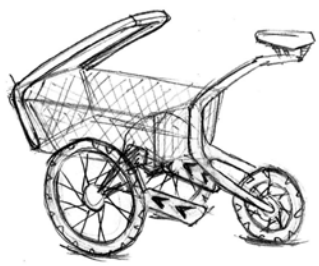
In this chapter I will explain how the SMDLP concept came forth from results found in analysis. With use of systematic approaches the initial idea has evolved into a more and more detailed design. So this design in fact is an answer to the 'problems' found in the analysis.

The idea generation phase started with morphological mapping; a systematic approach for creating solutions in principal. An also called "principal solution" basically is a package of functions bound in a rough sketch. This is an idealized solution (sketch) representation of the structure of a system in which the characteristics of the elements and the relationships that are essential for the technical operation, are qualitatively determined.

In addition, parallel to this sketching process, the "structural variation" method was used. This method helps to come up with alternatives at a topological level, which may not seem logic at first sight. This diverging approach gives a better insight onto the complex design problem.

10.1. Idea sketching





Above standing sketches were selected as most meaningful for further idea improvement. These very first ideas globally contain functions that might be promising. Take a look at *[Appendix VI; Idea sketching]* for some more idea sketches.

The main idea is that a minimalistic transportation device is used for transporting a person and some additional loads (shoppings). The shoppings are situated at the front and will get placed inside a basket or bags. The sketch at the left shows a 4-wheeled cart with a stepping propulsion mechanism. The cart is very compact and the gravity centre of the vehicle is very low; stability is a very important issue. In the middle a sort of tricycle is displayed. This alternative carrier cycle has two big spring powered clamps at the front where two canvas shopping bags can be put in between. The idea is to create two separate configurations, one for riding and one for shopping; therefore the vehicle has to transform from one configuration into the other. The picture at the right shows an alternative carrier cycle too; in this case a basket is integrated into the frame and a stepping propulsion system at the front in suggested.

10.2. Structural variation

Structural variation concepts are solutions in theory; the product is not materialised yet, but the principle or structure of a product idea will get determined. Both the placement of elements and the movement of elements relative to each other (typological level) are discussed here. By organising the structure of the product the product gets its meaning.

This method was used to explore and determine variations in search areas such as; riding, strolling and folding. Beside these three usage configurations the combination of a trolley and a bike was explored by experimenting with volumes and their orientation. Also a little study about the basket (shoppings mass and volume) location and orientation was executed. See *[Appendix VII; Structural variation A, B, C, D and E].*



With help of this method the idea of creating an X-shaped frame started to exist. As you can see in the pictures above two configurations are suggested; one for riding and one for strolling. The X-frame is quite easy to fold and makes it possible to transform one configuration into the other. The propulsion system is situated at the rear wheel; two step pedals are used.

10.3. Configurations

		
Riding mode: • Unfolded • Carrier bike configuration • Pneumatic tires • Pedalling • Stable, with loads • Stays outside	**Walking mode:** • Semi-folded • Shopping cart configuration • Plastic wheels • Strolling • Stable, with loads • Stays at supermarket	**Stand-by mode:** • Vertically folded • Stroller configuration • Plastic wheels • Strolling • Unstable • Stands in hallway, can be taken inside the room

When looking at yet existing products, comparisons in structure can be discovered. In fact a carrier cycle, a shopping cart and a baby stroller will get combined. In the diagram above the configurations are defined with use of a picture and some keywords. These configurations globally explain the intended usage of the yet to design product. These configurations made me revise the initial ideas, and a more detailed process of diverging was started, the results are displayed at the appendix *[Appendix VIII; Diverging].*

10.4. Appearances

The above standing ‘appearances’, which can be solutions in principal, are an exploration into both the intended product style and function. These principal solutions are basically the function carriers from which a final draft could be built. When combining different functions (riding, carrying and folding) in terms of visuals (wheels, basket, hinge) a spatial structure arises, which is crucial for the overall function. *“A principle solution is an idealized view of the structure of a system in which the characteristics of the elements and the relationships that are essential for the technical operation, are qualitatively determined”.* *[N.F.M. Roozenburg and J. Eekels; Productontwerpen structuur en methoden; page 109].* The bicycle/tricycle is a starting point onto which other functions can be attached. This strongly influences the character or context of the product, as one can see in the pictures above.

10.5. Rapid embodiment


In order to investigate geometry and related folding possibilities a way of ‘rapid embodiment’ is found in the usage of building toys. These plastic beams, wheels, hinges, bocks etc were used for making ideas physical at this early stage.

With these models it was possible to investigate at a basic level whether it was possible to transform from one configuration into another. More importantly it helped to understand the complexity of the design problem. While making these rapid embodiments design variables became clearer; understanding of decisions made in one configuration and the consequences of this decision made for the outcome result of another configuration. With a kind of trial-and-error an optimum was searched for various design aspects.

The design of a foldable frame is such a complex design problem; on paper it seems to work fine, but in practice a physical model proved otherwise. I made some alternative frame designs and investigated what geometry was most favourable for all configurations.

The location of the shopping basket inside the frame was also an issue. Namely, while riding the basket should be located more at front (to create free space for users knees to bend and pedal), but lower (look over it while sitting, and low point of gravity) when comparing to a walking/shopping mode. When walking de SMDLP during shopping a compact (user is behind it) device is preferred, where the basket is positioned at a higher location (user does not have to bend deep when putting items inside the basket). Two basket locations means a system/geometry that defines this location per configuration is required, plus the basket has to move along when transforming. In fact a system is needed to create a path, in which the basket moves during transforming. Some possibilities regarding this issue were investigated and validated with help of the plastic toys.

11. Storyboard

Storyboarding is a very powerful tool to help imagine a scenario; in this case a future usage of a yet to design product. The storyboard will help understand the current situation on one hand and plan out future interactions on the other. The 'story' does contain two dimensions: the first dimension is time: what happens first, next and last, and the second dimension is interaction: how does the persona interact with the product.

I made two storyboards *[Appendix IX and X, Storyboard]*; one about the current situation and one about the ideal situation. In this way I was able to imagine what could go 'wrong' during supermarket visiting in the current situation and how this must go 'better' in the ideal situation. This will be presented in bullet points below:

• In the current situation the persona has to gather shopping equipment (bag in this case) and a transportation device (stored outside in shed). Both are stored at different locations, resulting in a quite long preparation time. In the ideal situation these items are merged to each other and present (stand-by) at the same location (living area), so that the preparation time will be minimised.
•When arrived at the supermarket the persona has to park and lock the transportation device outside in current situation. Inside the supermarket itself a new shopping tool (shopping cart, trolley or basket) has to be gathered. It would be ideal when the transportation device becomes the shopping tool itself. The cycle has to transform into a shopping cart, so no parking space, lock or additional shopping equipment is needed. This saves time and is easier in usage because people do not have to re-bag all the shoppings from one tool into another.
• In current situation people have to gather their shoppings while using a shopping cart or some sort of basket, not knowing how many items will fit inside their own bag. People have to guess how many shoppings they can bring along. This problem can be solved when using the same tool for gathering shoppings and transporting them. In an ideal situation the SMDLP will be used inside the supermarket as an alternative shopping cart, people now exactly know how many shopping they can bring along because they use the same basket for transporting the items back home.
• At the cash desk the shoppings are put onto the conveyor belt, they got scanned and when paid they have to be collected again. In current situation all items have to be bagged because the supermarket visitor is not allowed to take a shopping cart or basket, which belongs to the supermarket, back home. In an ideal situation it would be handy to use a personal shopping cart that can be brought home.
• In current situation all the bought items are inside a big bag, resulting in discomfort and steering difficulties while riding a bicycle for instance. The persona has to hold the bag with one hand, which is hard work, and uses the other hand for steering the bicycle. In the ideal situation the shoppings are still inside the basket of the shopping cart which is transformed into a tricycle. The user does not have to hold any shoppings and can use both hands for steering. This is way more comfortable, effortless and saver.
• Arrived back home, in current situation, the persona has to put the bag onto the ground in order to store the bicycle inside the shed. The bag has to be carried all the time, but it would be more ideal if the SMDLP comes along inside the house and can brought inside the kitchen al well.

12. Function analysis

While developing a new and innovative product, certain working principals are needed to make the device functional. I am 'not reinventing the wheel'; so I will use common principals which proved their functional strength in the past. I state that an innovation can be a "new combination of components"; the total will deliver an innovative product in its use.

The 'function analysis' method is a systematic tool which helps to indicate what kind of working principals are needed and are suited the best; this will explain the main functions of my new design without a visualisation of the final product:

Below proposed working principals came forth from the idea that;
1) Vehicle is in balance during both cycling and shopping → at least 3 wheels are needed → shoppings are situated at the front (carrier cycle layout) → Ackermann steering geometry.
2) Simple folding geometry → comparable with folding an ironing board (shape and actions) → Foldable X-frame.
3) Because of wheel layout and X-frame a steering mechanism should be foldable too → cable steering.
4) The frame should be foldable but ridged → configurations must be locked automatically in the hinge → spring loaded quick release hinge.
5) User power is needed for transportation → this input must be transferred to the rear wheel → compact, reliable propulsion gears are needed → shaft drive.
6) Vehicle has to 'carry' some shoppings → use any kind of crate → crate carrier.
7) Vehicle must be suitable for a big range of people, differing in body length → differences in arm reach → adjustable steer stem.
8) Vehicle must be suitable for a big range of people, differing in body length → differences in leg length → adjustable seat.
9) Vehicle has to steer during both cycling and shopping → seat is blocking steering movement in shopping mode → foldable seat.

Below (section "13. Concept design) I will give a more specific explanation why certain working principals (functions) are chosen and preferred above others (sometimes more conventional ones).

13. Concept design

In this chapter the concept design phase will be explained. Decisions were made previously with help of several analysis methods and systematic idea generating methods. At this stage the findings from previous work will get implemented into a concept design. At first the concept direction will be explained with help of some "concept drawings"; this can be seen as graphically defining the concept. Secondly the design steps made towards a final design will be explained into the "concept development (evolution)". This chapter will be finalised (design freeze) with the explanation of the final design proposal in the "concept elaboration".

13.1. Concept drawings

The most important, and/or interesting findings from previous design methods were reviewed and combined in various concept drawings. The most meaningful concept drawings, which in fact visualises the final design direction, are displayed in the pictures above.

The concept has a simple folding mechanism in order to achieve various configurations, such as riding mode and shopping mode. In riding mode the user will sit onto the seat while propelling the step-pedals in order to drive. In shopping mode the user will stand behind the folded vehicle and push it in order to move.

Till this stage it was not decided whether the vehicle should use a shopping crate or a canvas bag. The concept drawings were used in order to validate both options and the shopping basket seem to be the most promising of both. The blue coloured concept drawings show the basket version of the concept, and a similar concept could be based on a canvas bag, as displayed in orange.

With these concept drawings most important findings could be visualised. In other words the decisions made, were captured inside the drawings and these drawings are a guidance for further concept development. The decisions made during concept development will be explained in the following section.

13.2. Concept development (evolution)




In the four pictures above, a short overview of the concept development is displayed. Many design steps were made and many changes were needed for concept optimization. Some of the most important concept development steps (which made an idea evolve into a concrete design) made will be discussed.

The first 3D CAD design of the SMDLP concept is displayed at the left; it shows a very simple frame made out of bended tubes, held together by one single hinge in the middle. The rear wheel is mounted inside the fork shape part of the middle section of the frame. The two front wheels are connected at the endings of the other frame sections (there is no connection/relation between both front wheels yet). The hinge is located underneath the point were the two frame sections intersect and create an X-shape. The consequence of the hinge situated below the intersection is that the two frame sections in a way of speaking want to move trough each other. Therefore a big opening underneath the seat is created inside the frame geometry so that the steer section can slide trough for folding purposes.

In the second picture from the left, the hinge was relocated and set on top of where both frame sections intersect, this very simple adjustment solved the problem of the two frame sections sliding trough each other. In this second version also a shaft drive was implemented for propulsion, this already defined most of the rear section of the frame. For instance the rear wheel is mounted onto the shaft drive and replaced the fork. The way of folding is also improved in this version because now the two front wheels are connected to each other by a hinge. This makes it able to bring both front wheels close to each other while remaining parallel. At this stage it was not possible to implement a steering mechanism that could fold along with the front wheels.

This was invented in a later version (third picture from left), at least the beginning of it. Implementation of such a steering mechanism became possible when realised it was possible to use steel cables for steering. Cables are flexible, and this flexibility is needed for making such a mechanism fold. Mayor improvements were made when the wheels were disconnected from the frame and independent suspension system was implemented. This suspension was connected by a pressure spring onto the frame; this spring pushed the device into its folded position when released.

The picture at the rights shows the concept design of the SMDLP one version before the final design. In this version the shape of the frame was revised this with proviso of a more sloping angle of the rear tube frame and a higher location of the basket. The basket is situated more above the two front wheels instead of in between, this due to better steering capabilities; wheels have more space to corner. Also a crate hanging system is introduces, existing out of a hook integrated into the hinge and two supporting plates that tilt along. These two elements carry the weight of the basket and define a path in which the basket moves when shifting configurations. At last the location of the main hinge is relocated again, now it is situated at the front because here it is easier to reach the turn button for locking/unlocking. These findings were used to create the final design, in the next section “13.3. Concept elaboration” the final design will be explained in detail.

13.3. Concept elaboration

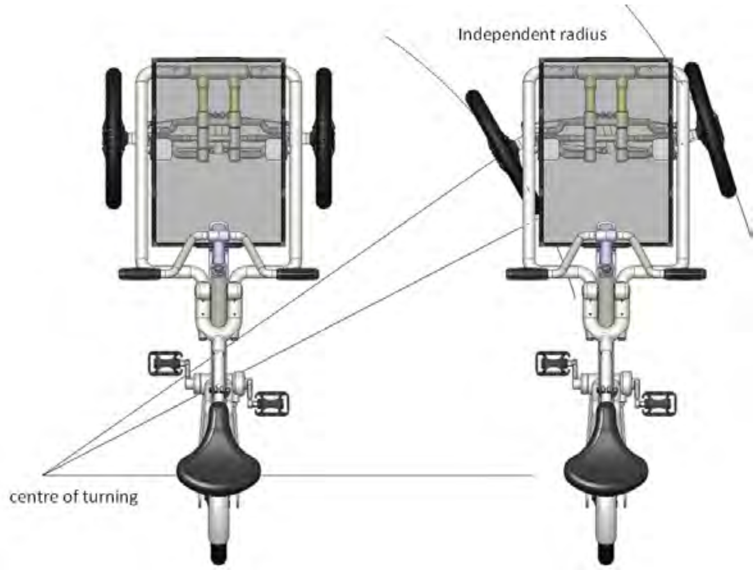
13.3.1. Working principals

In the following the concept elaboration will be explained according the various working principals that are embedded in the SMDLP concept. The position of the working principals are displayed in the picture below and will be described more detailed later in this chapter.

Steering mechanism

Because the vehicle has two front wheels a sort of steering mechanism is needed in order to steer, and turn smoothly. The typical cargo cycle steering, in which the two front wheels remain parallel at al times and are able to turn because of one single hinge connection, is outdated. Disadvantage of this way of steering is the fact that a big swerve of the steer is needed. In other words, the vehicle is separated into two parts that are related to each other by one hinge. The cargo basket and the two front wheels have to nod into a turn, by swerving the steering bar sideways. This requires a lot of effort because the load of the basket has its influence on the requested steering power.

An alternative is found at the automobile industry, where the Ackermann steering geometry gets implemented frequent. This system allows the vehicle to remain rigid, and gives the two front wheels the freedom to pivot independent in order to determine the turn.

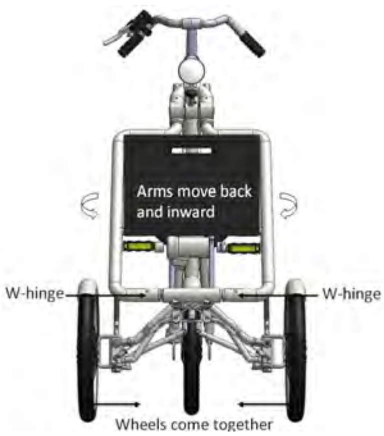


In the picture above the two driving situations are displayed; at the left the front wheels are parallel resulting in riding straight forward, and at the right the two front wheels pivot around separate hinges resulting in taking a turn. The Ackermann steering geometry is feasible because of a clever rod mechanism which interconnects the wheels to each other; there is a defined linkage between the wheels. When turning the front wheels are not parallel to each other anymore; they have an independent turning radius which eliminates nuisance slipping.

3 configurations
As mentioned before the concept has three configurations; 1) riding mode, 2) walking mode and 3) stand-by mode. This allows a user to drive to a supermarket, fold it into walking mode to use it as a shopping cart, and it can also be folded even more compact for temporary storage.

In the left of the above picture, the riding mode is displayed. This mode's functionality can be best compared to a carrier cycle, only this version is smaller, comparable to a folding cycle. The mode, displayed in the middle, is the walking mode and can be best imagined as a small shopping cart. The stand-by mode is displayed at the right, and is folded. The folded SMDLP has a 'box-volume' of 0.33m^3 (height 1.32m x length 0.66m x width 0.38m) in comparison with the 0.99m^3 (height 1.04m x length 1.44m x width 0.66m) of the riding mode; the volume is reduced with 300% by folding it. The floor space needed for the folded SMDLP is only 0.25m^2 (length 0.66m x width 0.38m) while in riding mode a floor space of 0.95m^2 (length 1.44m x width 0.66m) is needed; this is a reduction of 380%. The calculation demonstrates the necessity of folding the vehicle when it is required to store the SMDLP somewhere inside the living space of the user.

Foldable X-frame
To make folding the frame as easy as possible an X-shaped frame was designed. The frame exists out of two separate parts that are connected with a single hinge. The way of folding is comparable with the mechanism of an ironing board. First you have to unlock the hinge by pulling or turning a handle, at that time the hinge is free to move and now it is possible to swift to another set-up. Folding the X-shaped frame makes it possible to swift between riding and walking mode and vice versa. In the left picture below it is displayed where the X-hinge, that is responsible for folding and unfolding the X-shaped frame, is situated. When turning the button, the hinge is free to move, gas springs push the frame to above, making the rear wheel and front wheels come together.

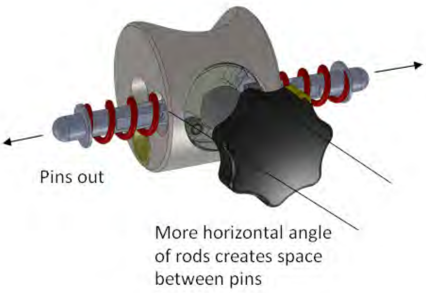


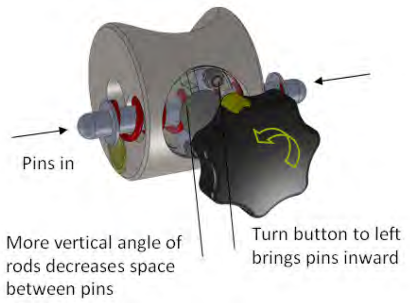
In the front part of the vehicle another folding mechanism is implemented; this makes it possible to bring the two front wheels towards each other. This makes it possible to swift between walking and stand-by mode and vice versa. There are two hinges integrated in the 'arms' of the frame, the W-hinges. They can only rotate when the vehicle is in walking or stand-by mode, due to the angle they are put in to. When the vehicle is in riding mode the hinge makes a 60˚ angle with the vertical, but it can only rotate when put in a 20˚ angle. In other words the rotation of the W-hinges is blocked in riding mode because the rods rotation path and the slot it has to move trough are no longer aligned.

The frame itself is made from standardised round metal tubes that are bended and welded together. Metal is chosen because of the limited material needed for making a rigid, strong and durable frame. Beside some exceptions (wood, plastic and even card board is used on experimental basis for frame building) all other, commercial bicycle frames are made out of steel or aluminium. Steel and aluminium are relatively strong (can carry much weight and do not break easily) and weather resistant when coated. Frames made of steel are heavier than aluminium frames; this is due to standardised tube dimension and not because of strength issues only. I can explain this by comparing the strength-density ratio between the two materials. (Steel (strength/density) = 210 GPa / 7.85 gcm^{-3} = 26.8 and Aluminium (strength/density) = 69 GPa / 2.7 gcm^{-3} = 25.6). In fact the ratios between strength and density are comparable, but steel is much cheaper and is therefore preferred above aluminium.

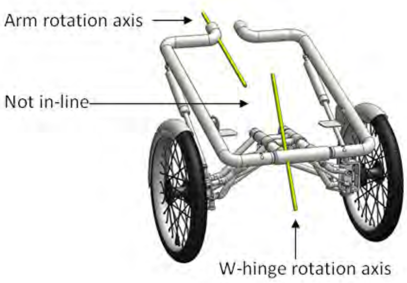
Fixating

The vehicles frame is foldable in order to create the three different configurations, but in order to hold a certain configuration the frame should be fixated into that position. So the X-hinge allows a change of modes between the riding and walking configuration, and uses a spring loaded quick release mechanism to fix into certain modes. When in riding configuration one has to turn a button in order to 'unlock' the X-hinge. When turning the button to the left (as displayed in the underneath picture) the pins that fixate the hinge move inward, allowing the hinge to rotate. In this situation the gas springs extend, pushing the frame upward; the frame folds itself (passively folding).



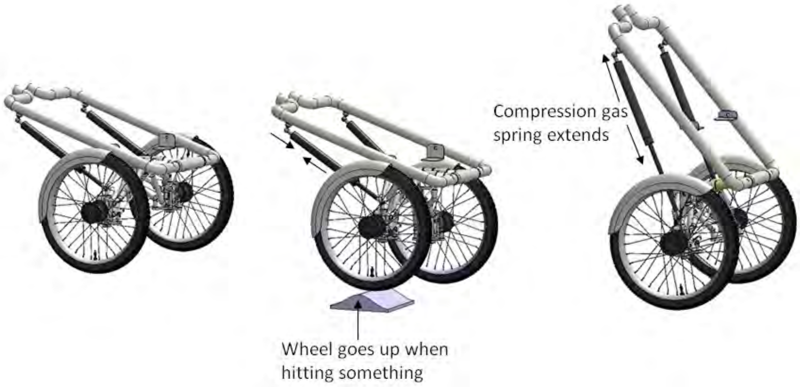


When one wants to turn the vehicle from walking back into riding configuration, the pins has to be removed out of the corresponding holes they were put into earlier for securing the walking mode. To do so, one has to turn the button again, and apply weight onto the vehicle's seat (actively unfolding). Now the hinge rotates back and the spring powered pins will slide back into the holes corresponding with the riding mode.



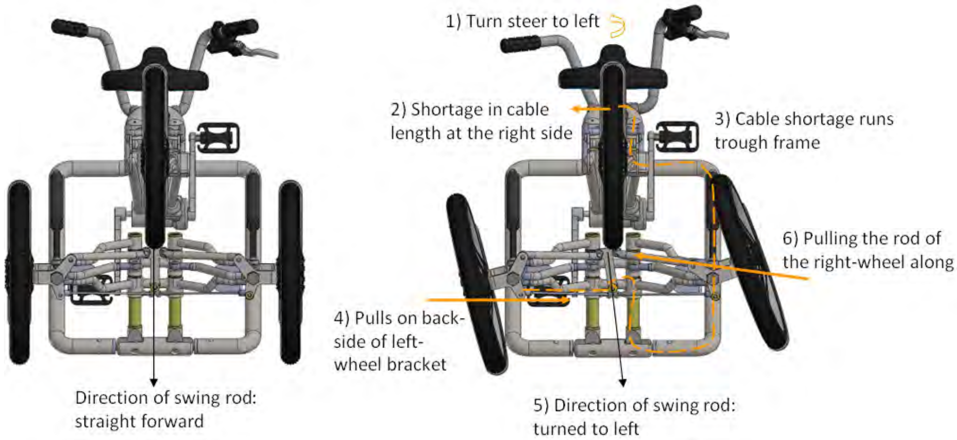
Another way of fixating hinges is implemented by making use of the geometry of the vehicle and the way it folds. In the picture above one can see that it is impossible when in riding mode (left picture) to fold the 'arms' of the frame in, because the arm rotation axis and the W-hinge rotation axis are not in-line as mentioned earlier. In the walking mode (right picture) these axes are in-line, making it possible to change between walking and stand-by mode. The yellow line represents the common axis on which the arm of the frame can fold inward when moving into stand-by mode. The W-hinges are locked with spring loaded pins, this is a similar principle as the pins used in umbrellas, or the larger steel tent poles for instance. This means the pins have to be pushed in to allow rotation in the hinge.

Suspension
The suspension system is situated at the front of the vehicle; it is integrated between the two front wheels and is part of the folding mechanism as well. The suspension uses compression springs for shock absorbing and for changing in configurations of the SMDLP vehicle.



In the picture above at first the suspension system in riding mode is displayed. The compression spring is slid in quite far in this situation, but there still is some spring length in order to absorb shocks. The vehicle is capable to absorb shocks while riding due to this independent wheel suspension; when hitting something the wheel goes up a little and the spring will be compressed a little more, absorbing the hit. In another situation the same compression springs are used in order to change from riding mode into walking mode. The springs will extend, gaining its full length when the X-hinge is unlocked as described earlier.

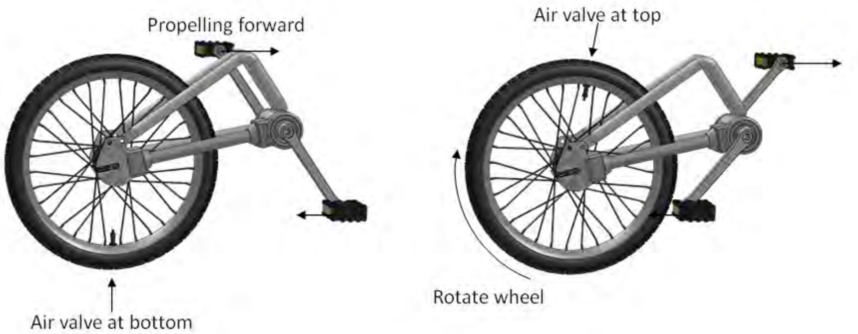
Cable steering
In the SMDLP concept a quite unconventional way of steering is used, this is necessary because of the X-shaped frame the steer is not directly connected with the front wheels. In addition a very flexible steering mechanism is needed for allowing folding actions in favour of shifting between configurations.



Cable steering is implemented as displayed in the above picture; it can connect the steer with the two front wheels and it is very flexible. When the steer of the vehicle is turned, a shortage in the cable is achieved. The steel inner cable slides in its plastic sleeve, transporting the shortage, or pull movement to the back of the wheel bracket. As a result of this the swing rod of the Ackermann steering geometry tilts, making the steering rod of the other wheel move inward. In other words the two front wheels are connected (relation between wheels is defined by the Ackermann steering geometry, resulting in independent turning radius per wheel) with each other, and when pulling one wheel into cornering the other wheel will move along, but has its own path.

Cable brakes
I decided to choose cable brakes as a braking system because this is by far the most flexible way to implement brakes. They are cheap and can be situated at any wheel. A coaster brake will only make the rear wheel brake and a special hub, which is more expensive, is needed to do so. Therefore cable brakes will get installed at all three wheels, when pulling the brake levers, the cables will shift in its sleeve, pulling on to braking blocks that will push upon the rims, making the wheel stop.

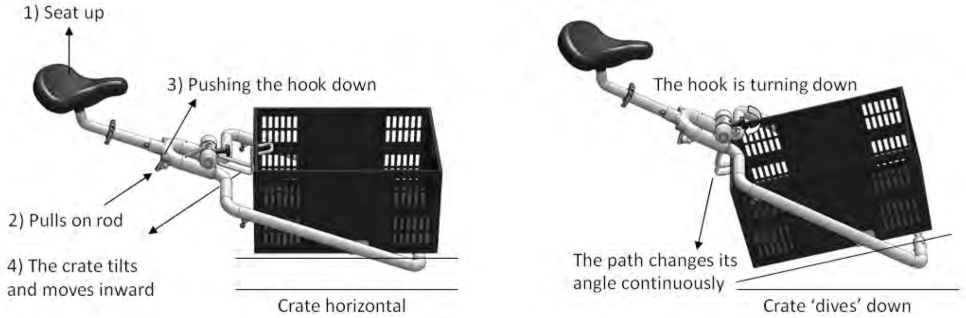
Shaft drive
This vehicle is a human powered concept; therefore the user's power input onto the pedals has to be transported to the rear wheel in order to get riding. To do so a propulsion system is needed, most today bicycles use chain drives to do so. But is this concept it is more suitable to use a shaft drive because it is more compact. Namely, when folding from driving mode into walking mode the frame folds in a way that it supports the carrier crate while shopping. A chain drive will get stuck outside the frame because of the bigger radius of the chain discs in comparison with the radius of gears used in shaft drives. Other advantages of a shaft drive are the fact that it is an enclosed mechanism; no dirt can infiltrate the system and no moist can get upon your clothing.



Using a shaft drive for this manner is nothing new, very old bikes had them in the early days but the chain drive had the advantage of making different gearing possible. With new technology it now is also possible to shift gears with a shaft drive. I did not implement gears into my design, because the device will only be used for short distances. It is always possible to implement gears by using hub gears; the single speed hub will be removed and replaced by a 3 or 7speed hub. Also notice that the cost price of a shaft drive is dropping because of competing Chinese manufacturers. I chose a 325mm long shaft drive from the Chinese "Space Cardan" Company suitable for 16 and 20inch wheels. Such a shaft drive is standardised and purchasable in big amounts for 12 – 20 euro per piece approximately. The shaft drive transports the rotary movement of the pedals through its angular gears towards the back wheel axis. This will make the 16inch back wheel spin, pushing the vehicle forward.

Wheels
Because of cost price, strength and weight I decided to use standardised 16inch spoke wheels. These wheels have an aluminium rim which is made out of an aluminium extrusion profile that was bended into a circle. The hub is connected with the rim by the spokes, which is the lightest solution to do this. The rear wheel has a conventional double sided connection to the frame, but the two front wheels are hung up single sided to the frame. This is a result of the way of steering; because of the Ackerman geometry the wheels have to swift and can not be locked up inside a frame.

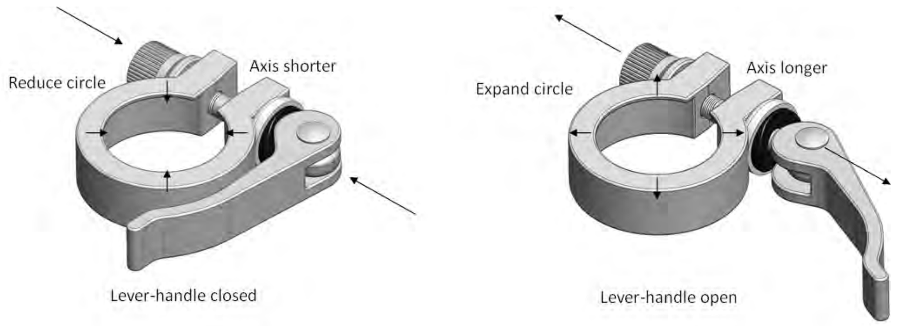
Crate carrier
The SMDLP vehicle has two configurations in which it holds a foldable shopping crate between its arms. The crate carrier is a combination of a hook and two small platforms that fix the position of the crate. When folding the vehicle from riding into walking mode, and vice versa, the crate carrier makes the crate following a certain path. This path is the route the crate has to follow during folding actions, with its two extreme positions riding-mode-crate-position and walking-mode-crate-position. Compared to the walking mode, the riding mode situates the shopping crate more at front and lower for instance.



When changing from riding into walking mode, the seat moves up as displayed in above picture. The folding mechanism is connected with the crate carrier mechanism, so when folding the X-shaped frame the crate moves along too. When the seat moves up, rods in the crate carrier mechanism push the hook (that carries the weight of the crate) down. Downward rotation of the hook makes the crate tilt and move inward, resulting in a 'diving' movement to its new position.

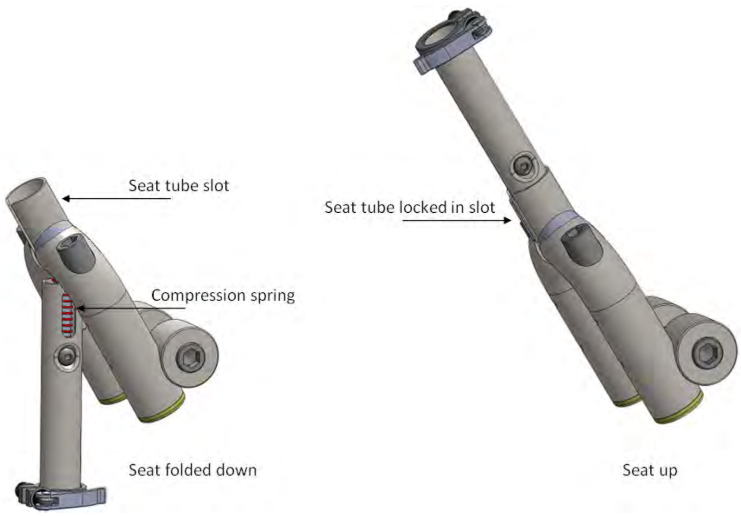
Adjustable steer stem
Because of the three different configurations, positions of the steer change during the use of the vehicle. In addition, a wide range of users should be able to ride and walk with the vehicle and therefore the device has to be compatible with different body lengths. To allow people with diverging body length in combination with the configuration settings, the steer stem needs to be adjustable. Adjustable steer stems are quite common nowadays, various bicycle brand produce these standardised parts, which can lock/unlock the position of the steer by pulling a lever-handle. The handle produces friction, making it impossible for the steer to slide or rotate in the stem. The advantage of the lever-handle is that no additional tools are needed to adjust the steer position, making it very easy and intuitive device to use.

Adjustable seat
The same principal as in the adjustable steer stem is used for adjusting the seat height; this seat locking/unlocking mechanism is displayed in the picture below.



When the lever-handle is closed the axis that connects the two ends of the clamp are pulled together because the axis was forced to shorten. This makes the clamp, represented by a circle, reduce in diameter. The smaller diameter will clamp the seat tube in the mechanism. But when opening the lever-handle the axis will become longer, making the clamp diameter expand and now the tube inside the clamp can slide up and down.

Foldable seat
The seat has to be folded down when shifting to walking mode. This is necessary because otherwise the seat will block the steering movements while walking with the SMDLP.



The seat can be folded down by pulling the seat tube out of its slot. A compression spring holds it in place by applying tension on the connection (similar as the elastic wire in bamboo tent stick).

13.3.2. Parts

Bought parts
Many of the parts in the SMDLP concept can be bought from part-suppliers or resellers. Wheels, bolts and nuts, rod ends, pedals, springs, clamps, cables, lights, and even the shaft drive, seat and foldable crate are more or less standardised parts that can be bought. Part-suppliers provide parts in various sizes and materials, making it possible to select the right parts for each occasion. Making such parts yourself does not make sense because of the high financial investments that are needed, and the lack of specific knowledge. Buying those parts simply is the more secure and cheaper solution.

Self-made parts
Although most of the parts can be bought, some parts have to be self-made. The SMDLP frame has a very specific geometry that is constructed out of semi-manufactured goods, like standardised tubes, sheet material and rods. The frame, the wheel brackets and the steering rods are some of the parts that have to be self-made because their geometry is specific for the SMDLP design.

13.3.3. Standardisation

Standardisation is the process of developing and agreeing upon technical standards. A standard is a document that establishes uniform engineering or technical specifications, criteria, methods, processes, or practices. Formal standards organizations, such as the International Organization for Standardization (ISO), are independent of the manufacturers of the goods for which they publish standards. The goals of standardization can be to help with independence of single suppliers (commoditization), compatibility, interoperability, safety, repeatability, or quality.

In practice this means semi-manufactured goods are produced according a certain standard. When designing parts it is wise to select a semi-manufactured item (any standardised tube, sheet or rod) and use this as the main component, and modify it in such a way the final part will emerge.

For instance the SMDLP frame is build out of standardised tubes, standardised sheet and standardised rods, which are all modified with various production methods in order to create the final part geometry. D60x4mm, D42x3mm, D42x2mm, D40x2mm, D36x3mm, D30x3mm, D35x3mm, D22x1,5mm, D18x1,5mm aluminium tubes are used to construct the frame. The X-hinge, wheel brackets and W-hinge are respectively made out of round staff of D50mm, D40mm and D32mm. The wheel bracket steering plates are fabricated from 6mm thick aluminium plate.

13.3.4 Materialisation

Selecting the right material for the SMDLP is very important because material selection has a big influence on weight, strength and durability. Beside the mechanical properties of the material, also its environmental impact has been taken into consideration. The CES 2010 EduPack software has been used for browsing trough material property and processing information, in order to find the most suitable material for the application.

In the end the 6061-T6 Aluminium alloy was selected as the main building material for most of the self-made parts in the SMDLP structure. 6061 is a wrought, precipitation hardening aluminium alloy, containing magnesium and silicon as its major alloying elements. (About 85% of aluminium is used for wrought products, for example rolled plate, foils and extrusions). It has good mechanical properties and exhibits good weldability. It is one of the most common alloys of aluminium for general purpose use.

The 6061 Aluminium alloy has a density of 2.70g/cm3 and the mechanical properties of 6061 depend greatly on the temper, or heat treatment, of the material. The T6 version of this material has an ultimate tensile strength of at least 290MPa and yield strength of at least 241MPa. More typical values are 310MPa and 275MPa respectively. The young's modulus is 69Gpa. In thicknesses of 6mm or less, it has elongation of 8% or more; in thicker sections, it has elongation of 10%.

Aluminium alloys typically have an elastic modulus of around 70GPa, which is about one third the elastic modulus of steel. For a given load, a part made of an aluminium alloy will therefore show greater elastic deformation than a steel part of identical geometry.

In general, stiffer and lighter designs can be achieved with aluminium alloys than is feasible with steels. For instance, increasing the radius (and weight) of a thin-walled tube by 26% will lead to a halving of the wall stress. For this reason, bicycle frames made of aluminium alloys make use of larger tube diameters than steel or titanium in order to yield the desired stiffness and strength.

Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required. When being more specific the 6061 Aluminium alloy is widely used in aircraft structures such as wings and fuselages, yacht construction including small utility boat, bicycle frames and components, automotive parts, as in many other applications.

6061 is highly weldable, for example using tungsten inert gas welding (TIG) or metal inert gas welding (MIG). Typically, after welding, the properties near the weld are those of 6061-0, a loss of strength of around 80%. The material can be re-heat-treated to restore -T4 or -T6 temper for the whole piece. After welding the material can naturally age and restore some of its strength as well.

6061 is an alloy used in the production of extrusions; long constant cross-section structural shapes produced by pushing metal through a shaped die.

6061 is an alloy that is suitable for hot forging. The billet is heated through an induction furnace and forged using a closed die process. Automotive parts, ATV parts, and industrial parts are just some of the uses as a forging.

Beside all the mechanical advantages aluminium provides over other materials, it also is a material that can be easily reused. Aluminium recycling is the process by which scrap aluminium can be reused in products after its initial production. The process involves simply re-melting the metal, which is far less expensive and energy intensive than creating new aluminium through the electrolysis of aluminium oxide (Al2O3), which must first be mined from bauxite ore and then refined using the Bayer process. Recycling scrap aluminium requires only 5% of the energy used to make new aluminium. Aluminium therefore is the most sustainable option for building the SMDLP frame.

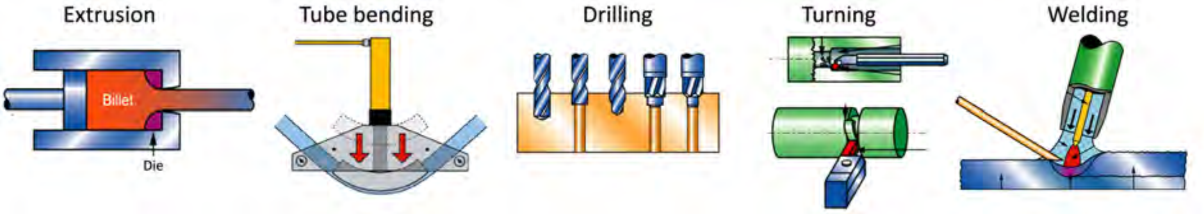
6061-T6 Aluminium alloy is selected because of its strength-weight ratio, ductility in various production methods, weldability and its sustainability. This combination of material properties makes it the most suitable material in case of building the SMDLP.

13.3.5. Production methods

In the previous sections of this chapter about concept elaboration it was explained what functionality is needed in the SMDLP concept, which parts can be bought and which parts will be self-made, the standardised sizes of semi-manufactured parts and the material it can be made of. Now it will be explained how the self-made parts could be made, and which production methods are needed to do so. In this section only the most common, and important production methods that can be applied for producing the self-made parts are discussed.

The SMDLP frame, wheel brackets plus bracket plates, steering and suspension rods and the hinges are all self-made parts. The frame will be build out of aluminium tubes; in order to produce these tubes a production method called 'extrusion' is needed. Extrusion is a process used to create objects of a fixed cross-sectional profile. A material is pushed or drawn through a die of the desired cross-section; in case of producing tubes a pipe extrusion die is used. The aluminium tube extrusion process is semi-continuous; a big press pushes a rod of pre-heated base material trough the extrusion die under high pressure. The material gets the shape of the extrusion die, and the out-coming profile is fed further by a traction device and cooled with water or air. Immediately after extruding the profile, the tube gets stretched till just above its 0.2% elastic limit in order to straighten the tube. The tube will be cut of in its desired length and will be heat-treated in order to receive its T6 temper.

The tubes and rods will be bended in order to create the desired part geometry, this will be done by an automatic pipe bending machine. Nowadays these machines can use 3D CAD file information in order to extract bend coordinates and orientations. The machine will make the required bends, in multiple planes and direction when needed, and cut of the part when finished. In similar ways the wheel bracket plates will be bended with help of a sheet bending machine out of 6mm tick sheet material into their required U-profiles.



The bended parts will be set in a tube cutting/drilling device in order to cut out the pieces in order to create a clean fit between the tubes. The tubes that have to be welded together will be placed inside some sort of mould; this clamping device ensures the tubes will be put together in the same exact geometry all the time. The tubes will be fixed together by a welding robot.

The parts that are made out of staff material have to be made by machining production methods such as tuning, boring, milling, drilling and parting. Their geometry starts to show when removing the superfluous material. The brackets and hinges are made with these machining production methods, which are also automatic and operate onto 3D CAD information as well.

So in short the following production methods are used:
1) Extrusion of the aluminium tube for the frame
2a) Bending aluminium tube for the frame main tube and arms, etc
2b) Bending aluminium sheet for the wheel bracket plates
3) Cutting and drilling tube geometry to create fits in the frame
4) Turning/boring/parting the wheel brackets and hinges
5) Welding the frame together

The numbers correspond with the above pictures, where 1 is the most left and 5 is the most right standing picture.

13.4 Calculations

13.4.1. Weight estimation

The initial goal was to design a vehicle below 16kg. In this weight estimation it is tried to indicate whether this is possible in combination with the design related decisions made earlier. In the chart below the collective weight of the self-made parts and the bought parts are displayed. The weights of the parts are estimated with help of the SolidWorks mass properties tool or are weighted on a digital scale.

From this weight estimation one can see that the self-made parts count for a collective mass of 12kg when most of it is made out of aluminium. This already is quite a high mass when compared to the 16kg goal. In addition, the weight of the bought parts add another 8kg to the total mass of the vehicle. The total weight of the SMDLP vehicle will be 20kg approximately in this calculation, and can only be decreased by selecting lighter materials or reduce the volume per part.

In other words 4kg weight reduction in the self-made parts is needed in order to reach the 16kg goal. This means (4kg/11.859) x 100% = 33,7% decrease in volume is required, which has serious consequences for strength. On may conclude that the initial 16kg maximum weight requirement is not achieved, and 20kg seems to be doable.

Part-(category)		Material		Weight
Collective weight of made parts				
Frame		Aluminium (2.70 gcm^{-3}) with steel bolts and nuts		8755 grams
Rods		Aluminium (2.70 gcm^{-3})		1167 grams
W-hinges		Aluminium (2.70 gcm^{-3})		828 grams
X-hinge		Compound: Aluminium + Nylon + ABS = New compound (3.35 gcm^{-3})		720 grams
Bicycle stand		Aluminium (2.70 gcm^{-3})		144 grams
Crate hook		Aluminium (2.70 gcm^{-3})		102 grams
Plain bearings		Nylon (1.40 gcm^{-3})		143 grams
			Sub-total:	**11.859 grams**
Collective weight of bought parts				
Wheels		Compound: Aluminium + Steel + Rubber (weighted)		2.970 grams
Folding crate		Plastic (weighted)		1.030 grams
Joints		Steel (7.80 gcm^{-3})		1.026 grams
Spring system		Aluminium (2.70 gcm^{-3}) and ABS PC (1.07 gcm^{-3})		426 grams
Pedals		Aluminium (2.70 gcm^{-3})		274 grams
Fenders		ABS PC (1.07 gcm^{-3})		122 grams
Shaft drive		Aluminium (2.70 gcm^{-3})		716 grams
Steer stem		Aluminium (2.70 gcm^{-3})		167 grams
Steering bar		Aluminium (2.70 gcm^{-3})		276 grams
Bracking system		Compound: Steel + ABS + Aluminium + Rubber		255 grams
Treadles		PVC (1.30 gcm^{-3})		230 grams
Seat		Compound: Steel + Rubber + foam		192 grams
Head light		Compound: Plastic + glass		125 grams
Back light		Compound: Plastic + glass		125 grams
Top tube bearing		Steel (weighted)		74 grams
Hand grips		Rubber (1.00 gcm^{-3})		64 grams
Ball bearings		Steel (7.80 gcm^{-3})		52 grams
Seat tube clamp		Aluminium (2.70 gcm^{-3})		48 grams
			Sub-total:	**8.172 grams**
			TOTAL:	**20,031 grams**

13.4.2. Cost price estimation

In order to be able to conclude whether it is possible to produce the SMDLP vehicle for a cost price below 700 Euro I will make a cost price estimation. The cost price per part will be indicated roughly by assuming the material costs (55%) per part can be used as an indication of the total costs per 'self-made' part. Labour, tools and machines all have a stake of 15% in this calculation method. There are also assembling costs involved; all costs involved with the made parts, plus the costs for the bought parts are responsible for 80% of the total costs. The resuming 20% are the assembling and connecting costs, which both have a stake of 10% in this matter.

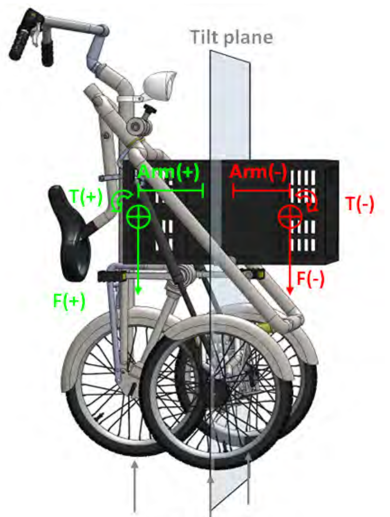
So the material that is selected, and the mass per part are the foundation for estimating the cost involved per made part. The CAD SolidWorks tool 'mass properties' is used for indicating the volume per made part. The volume will be multiplied with the material's density and the result of this will be an indication for the mass. Material price information from the CES2010 standard edition will be used in this calculation in order to link the part's mass with the material's price, this multiplication will be responsible for 55% of the final cost price per made part as mentioned before. The estimation of cost price per made part are displayed in the left column in the below chart.

Prices per bought part are from Internet resellers, like *www.fietsonderdelengroothandel.nl* and *www.conrad.nl*. Most of the prices found were validated as quite realistic, and are displayed in black. It is assumed that resellers take quite a high profit margin and parts can be bought in higher quantities for a lower price. Therefore the cost prices are reduced with 30%. Other prices are validated as unrealistic; because of the low selling volume offered and the resellers' ultimate-high profit margin, prices are way too high. These parts are displayed in gray, and it is stated that it should be possible to self-produce these part cheaper, or buy them for a lower price elsewhere. For some parts it was impossible to find price indication, these are also displayed in gray. The 'gray' parts are virtually transformed into the self-made parts column, where their cost price will be calculated according to the amount and type of material is used for producing these parts.

Costs per made part		Costs per (sub-)assembly		Costs per bought part
Machines (15%) = € 4,91		Assembling (10%) = € 24,75		3x 16inch wheels = € 68,70
Tools (15%) = € 4,91		Connecting (10%) = € 24,75		3x 16inch fender = € 29,85
Labour (15%) = € 4,91	→	Parts (80%) = € 197,96	←	3x Braking system = € 20,55
Material (55%) = € 18,02		Made parts = € 32,76 Bought parts = € 165,20		Folding crate = € 7,95 Shaft drive = € 16
Aluminium: 10,996 grams (1.62 USD/kg or 1.36 €/kg) = € 14,95 Compound: 720 grams (2 USD/kg or 1.67 €/kg) = € 1,20 Nylon: 143 grams (3.45 USD/kg or 2.89 €/kg) = € 0,41 Self-produce 'gray' parts, mostly metal: 1,742 grams (1 USD/kg or 0.84 €/kg) = € 1,46	←	-- 2x spring system =? 2x hinge spring =? 8x M10 ball rod end = 95,92 2x M10 clevis rod end = 9,18 2x M5 ball rod end = 23,98 4x M10 universal joint =? 4x M8 universal joint =? 2x M10 ball joint =? Bolts & nuts =?	←	2x Pedals = € 9,40 2x Treadles = € 3,80 Top tube bearing = € 2,80 4x Ball bearings = € 5,60 Head light = € 4,35 Back light = € 1,90 Steering bar = € 5,75 Steer stem = € 44,95 Steering cable = € 4,40 2x Hand grips = € 1,10 Seat tube clamp = € 2,05 Seat = € 6,85 *Bought parts total = € 236* *-30% = € 165,20* 'gray' parts
Sub-total = € 32,76		Sub-total = € 197,96		Sub-total = € 165,20
TOTAL = € 247,46				

From this roughly executed price estimation, as displayed in the above chart, one can conclude it should be possible to fabricate the SMDLP vehicle for a cost price of €250 approximately. The intension is to sell the vehicle for €700, resulting in a gross profit of 180% ((700-250)/250 = 180%). Selling the product for approximately 3x times the initial value is quite reasonable for this kind of product.

13.4.3. Walking mode balance



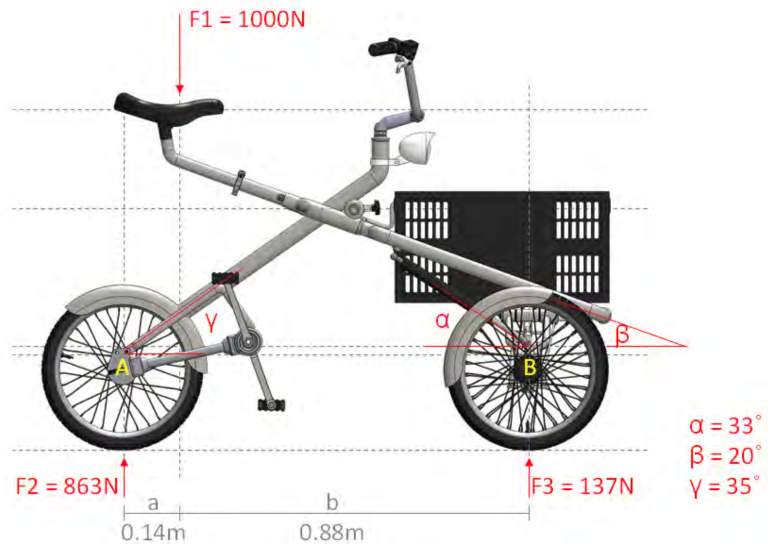
Whether the SMDLP vehicle will tip over while 'overloaded' in walking mode is investigated by the following described balance equation. It is assumed it is most likely the vehicle will tip over when putting all the shoppings at the front of the shopping basket only. The two front wheels are the points on which the vehicle can rotate; all loads at the right side of the tilt plane (coloured red) have a negative influence on balance and all the loads at the left side (coloured green) have a positive influence. The balance equation is visualised in the picture at the left. The own weight of the vehicle plus the shoppings are situated at the right side of the tilt plane; their combined load F(-) has a negative effect on balance because they create a dis-balancing torque T(-) which is depended on the distance of the point of gravity from the tilt plane, this is the Arm(-). At the left side of the tilt plane the own weight of the vehicle forms a counter weight, keeping the vehicle in balance. The torque T(+) has to remain bigger than the T(-) at all times in order to ensure balance.

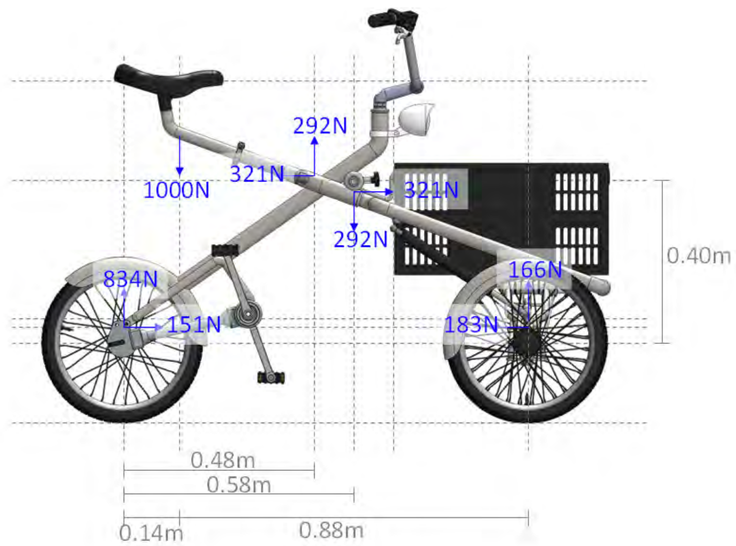
So; T(+) > T(-) when in balance. This means F(+) x Arm (+) > F(-) x Arm (-). When filling in this equation the result is; 15kg x 0,25m > (5+7,5kg) x 0,15m, this is <u>true</u> because 3,75Nm > 1,88Nm. And when putting 15kg in the basket instead of 7,5kg one would get; 15kg x 0,25m > (5+15kg) x 0,15m, this is also true because 3,75Nm > 3,00Nm. The vehicle will only tip over when someone is able to put more than 20kg in the front half of the shopping basket only. Because of the limited volume of the shopping basket it is impossible to create an 'overloaded' situation with shoppings only. The vehicle can tip over when adding more mass, a child hanging at the front of the basket for instance creates a significant higher torque because there is more weight and the arm is quite long. The overall conclusion from this calculation is that the vehicle will not tip over when loaded with shoppings, but a child hanging at the front can make the vehicle tip over in walking mode.

13.4.4. Bending under loads

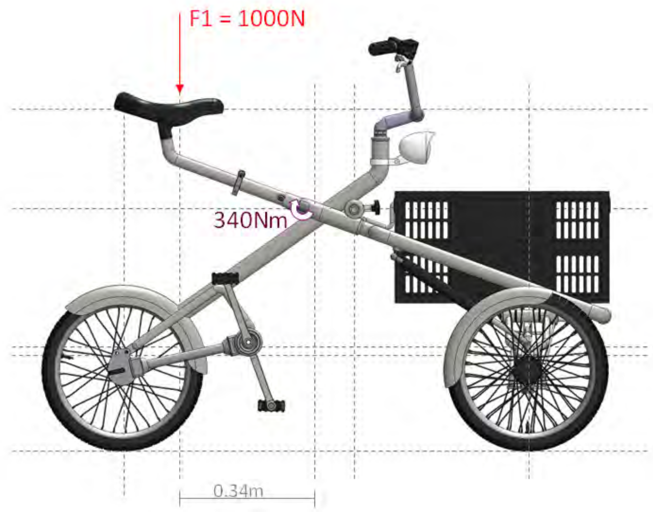
In the following the strength of the vehicle's frame will be validated with help of some mechanical calculations. It is demanded the SMDLP frame should be able to resist a P95 male body weight; this means a 102kg rider will produce a gravitational force (F1 = 102kg * 9.81 = 1000N) situated at the seat.

The 1000N force 'pushes' the vehicle with its wheels onto the ground. Where the wheels are in contact with the ground response forces F2 and F3 are expected. F2 = 0.88m * 1000N / 1.02m = 863N, F3 = 0.14m * 1000N / 1.02m = 137N, and whether this is true can be tested because F1(1000N) = F2(863N) + F3(137N).



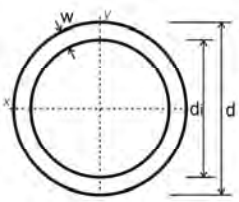


With the response forces it is possible to predict where forces are the biggest; this has a major influence on the stress in the material. In the above picture, the response forces in the material is calculated and displayed in blue. These forces are calculated in a 2D simplification, and therefore the forces at both the rear and front wheels have to be divided over the two frame sides. From this calculation one can see, the load produced by a 102kg rider is most crucial because the force it creates onto the seat tube probably will create the highest stress in the material. This is the occasion because the force works on a single tube that is suspended onto a single point, the X-hinge. Forces at the wheels are absorbed over triangular structures in the frame, and therefore their impact is less. The 1000N farce at the seat probably will push the seat down, making the seat tube bend a little. This same force is transported trough the frame, and at the X-hinge the main tube will also bend a little because of this. How big this stress in the material (6061-T6 Aluminium alloy) is will be estimated in the following calculation.



As mentioned in the above text, the 1000N force the rider produces is most crucial in the seat tube. The force gravitational, which means it only has a vertical component. The horizontal distance between the seat and the X-hinge, creates an 'arm' that will be used in order to calculate the momentum at the X-hinge. The momentum (M) can be calculated by multiplying the force with the 'arm' (M = F1 * arm = 1000N * 0,34m = 340Nm).

How much the seat tube will bend, and the amount of stress in the material can be calculated by adding information about the tube's geometry. The outside and inside diameter of the tube mass a major influence in this, as one can see in the below calculation.



Surface area:	$A = \pi (d^2 - di^2) / 4$	→	$A = \pi (40^2 - 36^2) / 4$	$= 238.8mm^2$
Moment of resistance:	$W = \pi (d^4 - di^4) / 32d$	→	$W = \pi (40^4 - 36^4) / 32*40$	$= 2{,}161mm^3$
Moment of inertia:	$I = \pi (d^4 - di^4) / 64$	→	$I = \pi (40^4 - 36^4) / 64$	$= 43{,}216mm^4$
Stress:	$\sigma = M / W$	→	σ = 340Nmm / 2.161mm3	= 157MPa

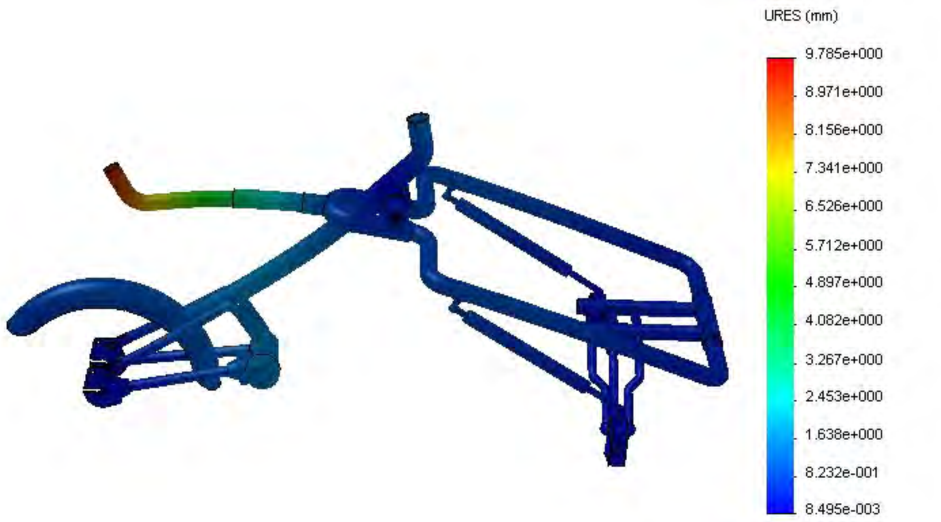
$E_{(aluminium)} = 69.000\ N/mm^2 = 69GPa$

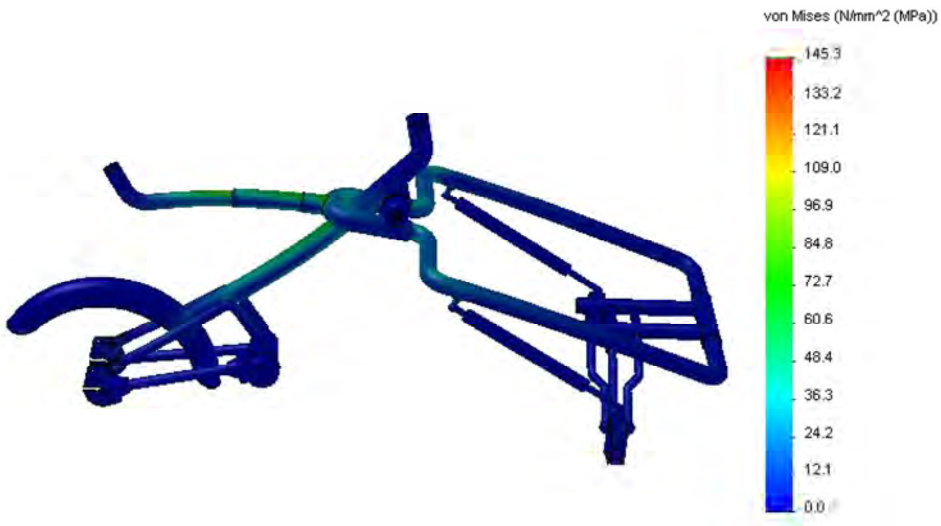
Deflection:	$v_{max} = -FL^3 / 3EI$	→	$v_{max} = -1000*340^3 / 3*69.000*43{,}216$	= -4.4mm

From these calculations one can see the predicted maximum stress inside the material probably will be 157Mpa and the deflection of the seat tube will be 4.4mm downward approximately. The estimated stress in the material does not necessarily cause any damage onto the vehicle because the 157Mpa is still lower than the 6061-T6 Aluminium alloy Yield Strength of 275Mpa.

13.4.5. Frame strength (FEM)

In previous calculation it was intended to estimate the maximum occurring stress in the material, and now this estimation will be validated with use of the Finite Element Method (FEM). In previous calculation I was able to calculate the deflection of the seat tube, but with FEM it is also possible to calculate the total displacement of the seat tube. In FEM the relation between all parts and their individual geometry does have an influence. It was already mentioned it is predicted also the main tube will bend a little. The deflection of the seat tube and the deflection of the main tube, as also the deflection of any other part will be summed up in FEM when calculation the displacement in the whole structure.



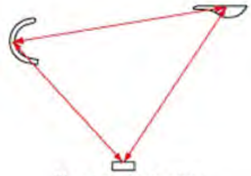


Finite Element Method (FEM) with 6061-T6 aluminium alloy resulted in a predicted maximum displacement of 9.8mm and a maximum stress of 145Mpa. This FEM analysis indeed shows (upper picture) the deflection in the seat tube has the biggest influence in the total displacement in the structure. A thicker seat tube, or a stiffer material for this part might be selected in order to minimize deflection in this part. The FEM analysis also shows (lower picture) the stress in the material will be no more than 145MPa. This means parts may bend quite a bit, but will also bend back into its initial position, without any damage.

14. Ergonomics

14.1. Three contact points

A consumer has certain mobility needs and uses multiple devices to achieve their goals relevant to moving. In order to operate a transportation device the user has to make contact with that device. In the case of this project it is most likely that a person has ***three possible contact point*** with the yet to design device, namely; the steering mechanism, the power input application and the person's weight carrier which divines an usage posture. Because of the contact between person and device, ergonomic factors are very important to improve comfort and efficiency.



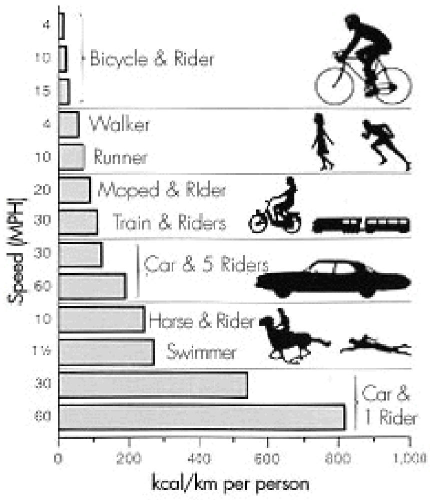
Three contact points

The most well know way of steering is the operation of the handlebars; bicycles, scooters, motorcycles and many other existing products found in section 3.1. of this report use this mechanism. The handlebar width should correspond with the width of the shoulders. According to the Dined Anthropometry data the P5-P95 of Dutch male shoulder width is 422-500 mm, and for Dutch females this is 378-470 mm. (*[Dined, 2004]*, Dutch adults 31-60 years). Handlebars that are too wide will result in a sagging between the shoulder blades. This will lead to complaints of the neck and shoulders. However, narrow handlebars often lead to more nervous steering than wide handlebars and, hence, to loss of comfort. In addition, the steering angle should be adjusted in such a manner that the lower arm and hand are positioned in one line, as much as possible. Another factor concerning the handlebars is the hand grip diameter, the recommended diameter is within 30-50 mm in circular cross section *[Pheasant, 1996]*.

Handlebar width

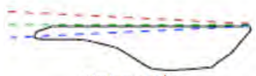
Steering angle

Hip and foot in line



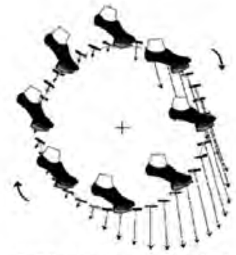
The power input for the yet to design device can be both human or electrical/fuel powered. One should be aware of the fact that cycling is the most efficient means of transportation, even more efficient than walking. The engine for this efficient mode of transport is the human body, were different muscle groups and types provide the power. It takes less energy to bicycle one kilometre than it takes to walk a kilometre. *"In fact, a bicycle can be up to 5 times more efficient than walking. If we compare the amount of calories burned in bicycling to the number of calories an automobile burns, the difference is astounding. One hundred calories can power a cyclist for five kilometres, but it would only power a car 85 meters" [Exploratorium, 2008]*.

Seat width



Sitting angle

In case of a human powered vehicle the power input is most of the times achieved by propelling pedals. While applying force to the pedals most adults can deliver 100 Watts continuously without getting tired, this results in a typical speed of 18 km/h. An important force in cycling is power output with every cyclist (recreational or competitive) having to overcome this in order to move the bicycle in different conditions. Being able to apply pedalling forces effectively is extremely important, while correct body positioning is crucial for successful performance and injury prevention. Only the force which makes the pedal rotate is useful, this force is applied perpendicular to the crank. The force is biggest when the crank is in a horizontal position and becomes much less in a more vertical position. Because of the rotary movement and the necessary force which has to be applied the foot is 'ankling'; this refers to the orientation of the pedal with respect to a reference frame fixed in the cycle. For matters



Ankling and power applied

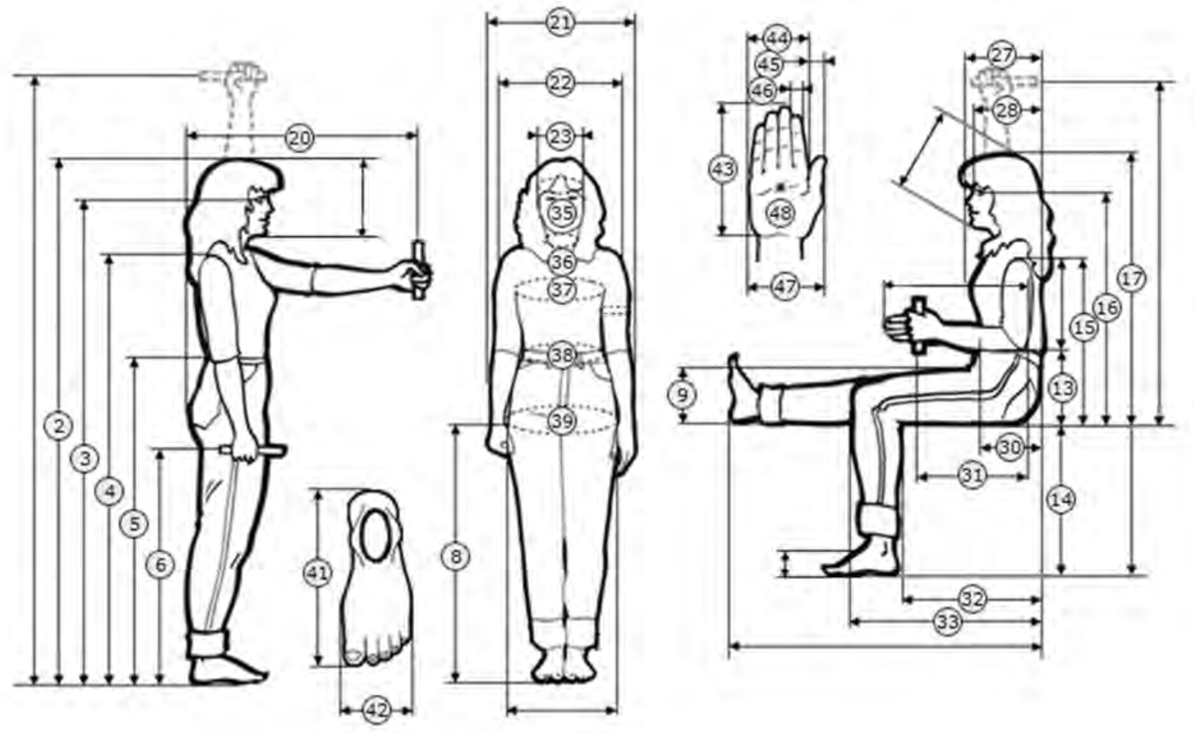
of comfort it is important that pedals offer sufficient stability, enabling the movement of the knee to remain in line-of-force with the hip and foot. The pedal should also be sufficiently wide because the entire front part of the foot must be supported.

The last contact point between person and device is the part that carries the user's body weight, in most vehicle concepts this is a kind of seat/saddle. According to Dined the P95 in body weight of Dutch males is 102kg, for females this P95 is 89kg. A saddle should fit comfortably; the width and shape of the saddle depend on the distance between the seat-bones and the shape of the pelvis. The larger the distance between the seat-bones and the rounder the pelvis, the wider the saddle should be. On the other hand, the width of the saddle also depends on the position of the upper body on the device. When sitting in a bend forward position, a narrow racing saddle is more comfortable and more functional (grating of the inner legs). When sitting upright, a wider saddle is generally more comfortable.

In principle the saddle should be placed horizontally. In case of a "positive saddle tilt" (saddle pointing upwards), the cyclist runs the risk of numbing certain parts of his body. As a consequence, the cyclist will be inclined to tilt his pelvis backwards which results in more pressure on the lower back. In case of a “negative saddle tilt” (saddle pointed downward), the cyclist will tend to slide forward. This is very uncomfortable not only because the narrower front part of the saddle gives too little support, but also because the arms, wrists and hands are subjected to too much pressure as a result of the cyclist trying to maintain a normal position on the saddle. The height of the saddle plays an important role in experiencing the bicycle as comfortable. If the saddle is placed too high, the cyclist runs the risk of overstretching his muscles; if the saddle is placed too low, however, the pressure on his quadriceps might become disproportionately high.

14.2. User anthropometrics

In this vehicle design project product measures should meet user anthropometrics in order to create a proper bike fit, resulting in comfortable body postures. The goal is to maximize comfort and efficiency, and to minimize the potential for injury, discomfort, and diluted performance. So bicycle geometry is very dependent on user body measures (this approach is very theoretical and proper bike fitting in practice is liable on personal preferences also), determining factors will be presented in the table below.



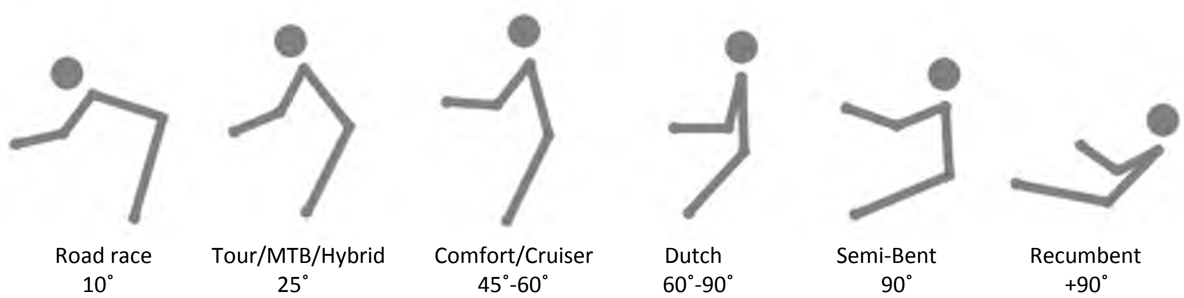
No.	Measure	Male MEAN	Male SD	Female MEAN	Female SD	Units
56	Body mass	80.8	14.3	66.5	9.6	Kg
2	Body length	1848	80	1687	67	mm
*	Inner leg length	835	46	685	46	mm
5	Elbow height, standing	1153	56	1050	50	mm
13	Elbow height, sitting	262	28	251	27	mm
6	Fist height, standing	826	47	770	38	mm
20	Arm length	763	43	676	36	mm
27	Chest dept	287	31	298	30	mm
*	Arm reach	476	12	378	6	mm

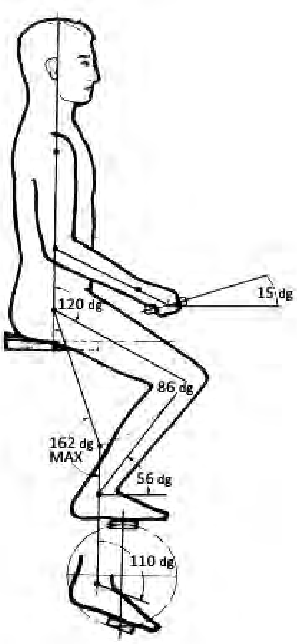
Dined 2004 (20-30 years, Dutch adults), values with No. * are calculated subtracts from other measures.

With help of these measures, gathered from Dined 2004 (20-30 years, Dutch adults) some design guidelines can be set. Values about the inner leg length were not present at Dined; therefore the values are calculated with help of data from M. Geentjens *[www.gesa.be/images/antropometrie.pdf]*. Additional data about the inner leg length in relation with body length (assuming that longer people also have longer legs) was found onto the Wielersportinfo-webpage *[www.wielersportinfo.nl]*.

14.3. Riding posture

Ergonomically speaking different types of bicycle can be distinguished according to riding posture. In the figure below different riding postures are displayed. Every posture is characterised with a type of bicycle, and its typical angle between the users back and the horizontal.





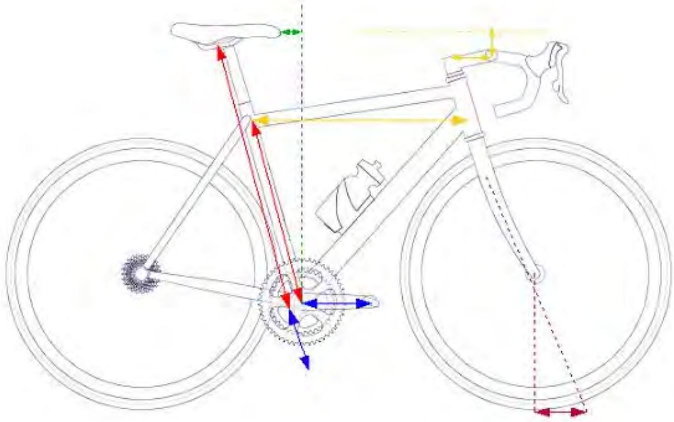
In this project speed performance is not that much important, but safety and comfort are. Remember that this vehicle design is applicable for supermarket visiting and therefore shorter distances, lower speeds and more crowded surroundings than for instance bicycle sports. So performance 'optimised' postures like the "Road race" and "Tour/MTB/Hybrid" are not the occasion here. Also the "semi-bent" and "Recumbent" postures do not show specific benefits in this case. With these postures the rider sits lower, and therefore it is harder to oversee traffic.

The requested body posture, namely something like the "Comfort/Cruiser" or the "Dutch", in combination with the user's anthropometric measures defines the future bicycle geometry; this will be explained into the following paragraph 'bicycle geometry'.

The posture itself is determined by 'angle limitations', as you can see in the picture at the left side of this page. With a straight back the knee-joint is limited by 162˚ max. and 86˚ min and the ankle-joint by 110˚ max. and 56˚ min. The wrist is in-line with the lower arm, which makes a 15˚ angle with the steer. The upper leg makes a 120˚ angle with the vertical when the foot pedal is at his highest point.

14.4. Bicycle geometry

"Bicycle geometry is the collection of key measurements (lengths and angles) that define a particular bike configuration. Primary among these are wheelbase, steering axis angle, and trail. These parameters have a major influence on how a bike handles" [Wikipedia].

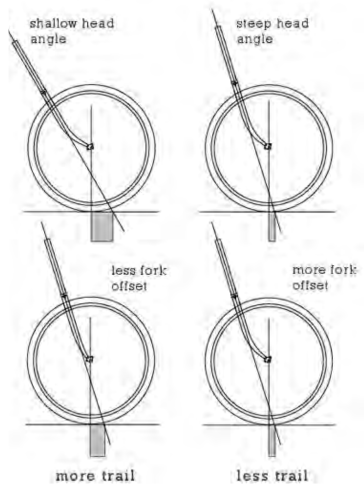


Bicycle geometry, relevant lengths

Wheelbase; is defined as the horizontal distance between the centres (or the ground contact points) of the front and rear wheels. Longer wheelbase add stability and comfort, but when the wheelbase is too long a bicycle will become slow in response. On the other hand a shorter wheelbase increases manoeuvrability, but will be unpredictable and could be dangerous when too short. Normally the wheelbase will be around 1000 mm, varying between 940 and 1070 mm. According to bicycle geometry, this design project can best be compared with folding cycles where a wheelbase of 1020 mm seems to be the standard (Brompton pre-2003, Dahon) although the new Brompton folding cycles have a wheelbase of 1045 mm.
[wheelbase=1020mm].

Steering axis angle; is also called the head angle or caster angle and is defined as the angle that the steering axis makes with the horizontal. The steering axis is the axis about which the steering mechanism (fork, handlebars, front wheel, etc.) pivots. The steering axis angle usually matches the angle of the head tube (which is the cause of the inconsistent name giving). This angle is directly related with the required trail (the bigger the steering axis angle, the shorter the trail will be), which will be explained below. This angle usually varies between 71 and 76 degrees. For city cycling a steering axis angle of 73 degrees seems to be quite common.
[Steering axis angle=73 degree].

Trail; is also called caster and is defined as the horizontal distance from where the steering axis intersects the ground to where the front wheel touches the ground. The measurement is considered positive if the front wheel ground contact point is behind (towards the rear of the bike) the steering axis intersection with the ground. Trail is often cited as an important determinant of bicycle handling characteristics. The bigger the trail is, the better a bicycle remains straight (stability) while riding at high speeds. A racing bike usually has a trail of 6cm, and a city bike has a smaller trail of 5cm; which results in a more direct steering and more stability at lower speeds.
[Trail=5cm].



The riding characteristics of a bicycle depends onto its steering geometry, as described by the three parameters above; which is one part of the total bicycle geometry. The geometry that determines the users riding posture is another very important part of the bicycle geometry. The riding posture will be defined by parameters like; seat angle, seat height, crank size, chainstay, top tube distance, saddle displacement and stem length.

Seat angle
A normal city bicycle usually has a seat tube angle of 66 to 70° approximately. This results into a lower point of gravity, leading to a more stable cycling posture. This comfort has a negative effect onto the riders ability to produce an optimal force input (an 71-72° angle increases efficiency and decreases comfort). So a more "relaxed" angle give a slightly more comfortable ride, but the important thing is that the riders knee has to be over the pedal otherwise you won't get the correct leverage and this is what regulates the seat angle.
[Seat angle=70°].

Seat height
Changing the seat height alters a number of variables in cycling including joint angles, muscle lengths and the force output muscles can produce. Research has reported the optimal seat height (seated in an upright position) to produce the most power output is 109% of leg length (maximum saddle height). In moderate intensity cycling, which is performed under steady state conditions, a seat height between 105% and 107% of leg length requires the lowest oxygen consumption (optimum saddle height), regarded as most efficient for events of lower intensity and longer duration. *(The length of the seat tube used to be dependent on the length of the riders leg, but since Mr. Burrows invented the compact frame design for Giant bikes this hasn't been the case and the length of the top tube has been more important to the fit of the rider as you use a long seat pin to make sure the saddle is at the correct height).*
[Seat height=105% leg length].

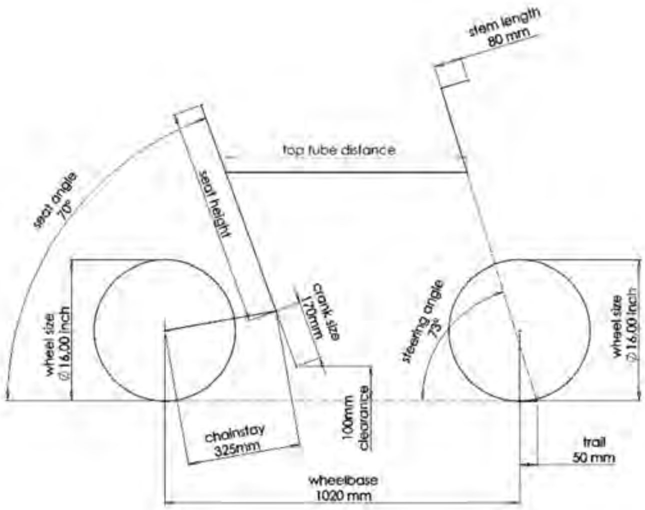
Crank size
The crank is the arm onto which the rider's pedal force will be applied to. In cycling sports the length of the crank depends on the riders leg length: leg lengths of 74-90cm are recommended to use a crank of 170mm; 90-92cm should use 172,5mm; 92-94cm should use 175mm and above 94cm should use a 180mm crank. For normal city bicycles this size is less relevant, therefore the standardized 170mm crank is used.
[Crank size=170mm].

Chainstay
From the centre of the rear axle to the centre of the bottom bracket. Longer chainstays add stability and comfort, shorter chainstays manoeuvrability. Short chainstay bikes are great for sprints and climbs. Long chainstay bikes are great downhill. In this design project the chainstay is less relevant, because it depends onto the available shaft drive lengths. The minimum shaft drive length applicable for a 16inch wheel is 325mm.
[Chainstay =325mm].

Top tube distance
Distance between the centre of the seat tube and centre of the head tube. Manufacturers of road bikes are increasingly using this dimension to specify frame size since compact frames and steeply sloping top tubes mean that seat tube length has become less relevant in defining frame size - as long as a rider can use a long enough seat post, a comfortable relationship between saddle and pedal can be established. The distance between saddle and handlebars, however, is much less malleable. Getting a precise fit in this direction is vital, especially for road riders and tourers. With sloping top tubes, the actual length of the top tube may matter less than the horizontal distance between the point at which the top tube springs from the head tube and where it intersects the seatpost - the "effective top tube". This length partly determines the distance between the saddle and the handlebars, called reach.

Bottom bracket height
Distance between the bottom bracket shell and ground. The lower the bottom bracket shell the more stable the bike but the more likely it is to scrape cranks during cornering. Mountain bikes have higher bottom brackets for clearance. The relative heights of bottom bracket and wheel axles also influence handling. Small-wheel bikes have high bottom brackets relative to their axles and hence feel slightly less stable. In city cycling a clearance of 80-100mm is acceptable, when adding the crank size (170mm) the bottom bracket height will result into 250-270mm approximately.

Now a better insight is gained into individual parameters that define the total bicycle geometry, it is time to map these lengths. In the picture below all chosen lengths and angles are combined. Although this is a first trial, trying to apply every parameter's optimum, it merely functions as a framework to play with. This means sometimes individual sizes should be adjusted negatively (away from their optimum) in order to create a bicycle geometry that is acceptable for as much users as possible.



14.5. Proper fitting


P5 female = 1577mm


P50 female = 1678mm


P50 male = 1848mm


P95 male = 1980mm


P5 female = 1577mm


P50 female = 1678mm

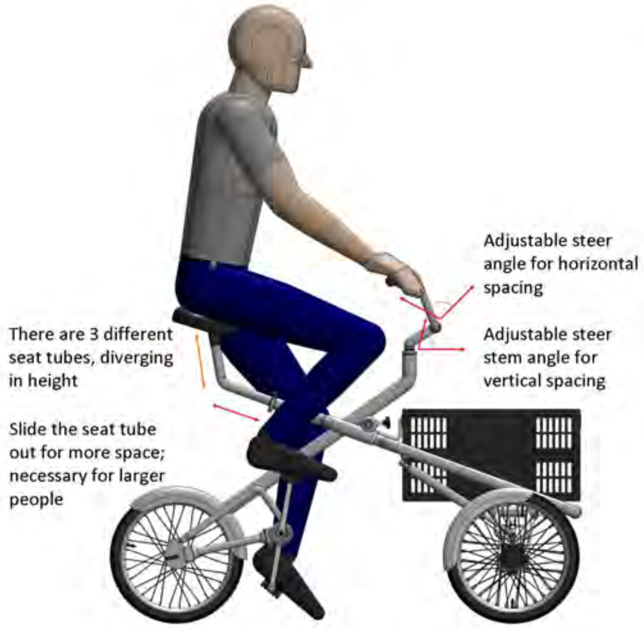

P50 male = 1848mm

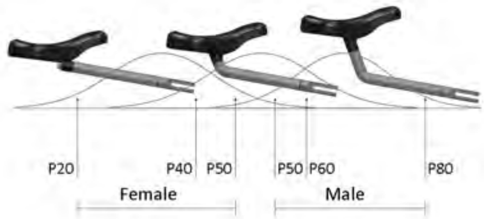

P95 male = 1980mm

So a proper bicycle fitting is dependent onto user anthropometrics, preferred riding posture and bicycle geometry. Limitations are indicated and combined into a summarizing model, as one can see in above pictures. From this fist investigation one can see the postures of the average male and female onto the SMDLP in riding mode seems to be quite reasonable. The shorter P5 female is almost standing, because the vehicle seems to be too big. The larger P95 male has not enough space for his legs and has to sit more at the back, making it necessary to bend forward a little in order to reach the steer. So the P50 male and P50 female do fit quite well onto the SMDLP but the range of people that fit is not knows yet; in the following this will be investigated more specifically. The required riding posture will eventually exclude some people from a proper fitting.

In the lower row of pictures the proper fit in walking mode is displayed. The range of P5 female till P95 male is displayed and it seems to be that all these people are able to reach the steer. The height of the steer in walking mode is 120cm approximately and this is 10-20cm higher than a conventional shopping cart. Whether it is necessary to drop this height down will be investigated in the prototyping phase (see chapter 15).

When looking at the riding posture more thoroughly it was discovered a perfect fit is impossible for a wide range of people that differ in body length. The 'angle limitations' as described in section 14.3 about riding posture are only applicable for one specific bicycle geometry in combination with one body geometry. So for the SMDLP vehicle there would only be one corresponding perfect body size. In a wider range of people the result of this is that comfort has to be sacrificed in order to make the rider fit the vehicle.





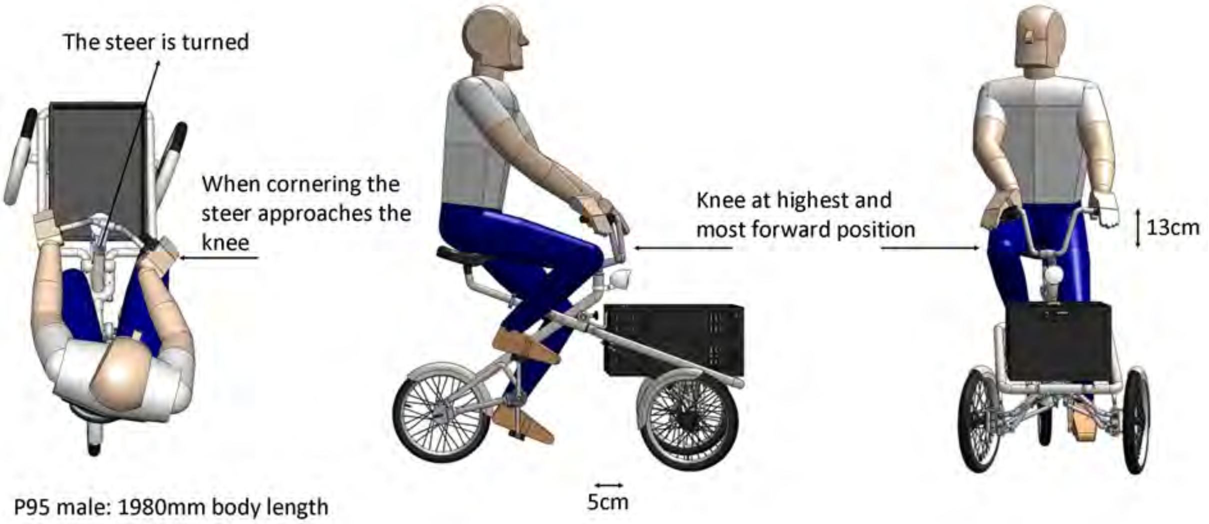
In the above standing picture a P70 male onto the SMDLP vehicle is displayed at the left. In order to make this rider fit the vehicle, a suited seat tube has to be selected (orange arrow), because this partly determines the seat height. The seat tube can also slide in- or outward (red arrow) in order to adjust seat height and the space between seat and steer. The steer and the steer stem angles (red angles) are adjustable as well in order to create a more, or less upright riding posture.

In general a larger rider will be positioned at a higher seat tube and the seat tube will be pushed more outward in order to create more space. The rider has to bend forward a little in order to reach the steer. The steer and steer stem angles will be adjusted to create a proper fit. From several investigations in SolidWorks it was discovered that average (P50 female and P50 male) people could be best positioned at the middle-size seat tube. The comfort peak of this middle-size seat tube should be somewhere between the P50 female and P50 male value, as displayed in the upper right diagram. Smaller people should be situated at the lower seat tube and larger people onto the higher seat tube as displayed in the same diagram. This diagram shows there are peaks and valleys in comfort over a wide range of body lengths, and with a set of three different seat tube sizes a range of P20 female till P80 male should be covered in terms of acceptable comfort. One has to note there is an overlap between the comfort curves of each seat tube size; for instance a P40 female could use the small or middle-size seat tube.

The SMDLP vehicle geometry is compared with a Dahon Curve folding bicycle in the above standing lower right picture. This Dahon vehicle has the same wheelbase and the space between the three contact points as described in section 14.1 is comparable. The only difference is that because of the crate positioned in the front of the SMDLP the three contact points in the SMDLP are closer to the rear wheel in comparison with the Dahon.

14.6. Collision detection (concept – user)

In this section collisions between the SMDLP concept and potential users will be detected. It is important to know if, and when collisions occur in theory. When getting insight in collisions it is possible to adjust the design slightly ore to exclude some types of potential users when necessary. Riding a cycle is a dynamic activity, in which actions like steering in combination with propelling may cause a collision of the knee against the steer. Most unfavourable situations (maximum steering angle and knee as high as possible for instance) will be used while executing this analysis.



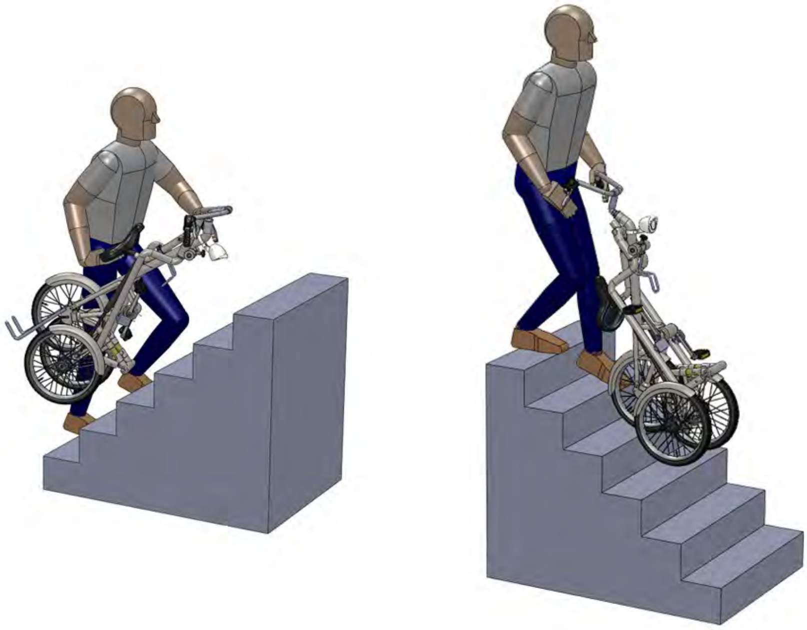
When riding the SMDLP vehicle it is most likely a large user (P95 male: 1980mm body length) will hit his knee against the steering bar during usage. It is expected that this type of collision might occur, ore at least it is most likely to happen when cornering. Taking a turn means the steering bar has to rotate slightly, and one of the bar ends will approach the rider's knee. In the above picture the described situation is displayed; even in this most crucial situation the rider is not in collision with the concept. There still is approximately at least another 5cm horizontal, and 13cm vertical space between the nearest knee and the steering bar.

Collision is also dependent on the circumstance in which the concept is used. For instance, above displayed collision detection is executed with a large user, but also the seat is in the right position for this large person. When creating an abnormal situation; seat totally in front (P5 female position) and placing the same large person in this posture of course collision occurs.

In order to perform this collision detection, it was investigated which user posture and positions of several crucial parts like the pedals, steer and seat (the three contact points, explained earlier in section 14.1) do have an influence. It was found that the vertical position of the pedals brings the rider's knee in the highest and most forward position. In this position it was most likely to hit the steer, because this was not the case it is concluded that in the total pedal-cycle no collision can occur. The steer and the seat had a somehow 'fixed' position in this analysis, because their positions correspond with the rider's body length.

From this collision detecting it is concluded that no collision between user and concept occurs while riding it 'normally', but collision might be possible in 'abnormal' usage. It is recommended to colour-code the steering bar and seat positions for diverging body lengths in order to prevent this kind of abnormal usage.

14.7. Up and downstairs



Another topic in which the SMDLP concept enters the field of ergonomics is taking the folded SMDLP vehicle up and downstairs. It was already imagined how this type of interaction between user, concept and situation would take place. This was visualised in the storyboard, see the appendix *[Appendix X, Storyboard – Ideal situation]*.

When taking the folded SMDLP vehicle upstairs the device can be carried by holding the steering bar and the seat. The user has to lift the total weight of the device, holding it diagonally while walking upstairs. Probably not all users are capable of carrying such a weight in a controlled way; they might bounce the device against the stairs or sidewalls. Whether someone carries the vehicle upstairs is behaviour depended and also someone strength has an influence.

Whether it is possible to lift the device in this carrying position a calculation about lifting comfort is made according the NIOSH-method (see *http://www.arbobondgenoten.nl/arbothem/lichblst/lifttest.htm*). This method uses a starting situation of the load (horizontal and vertical distance, and the angle of the load with respect to the person) and calculates the maximum load to carry under these conditions. A lifting index under 1 means someone can do this lifting action frequently without risk for injury, between 1 and 2 means someone can lift under this conditions but there is some risk, and an index above 2 means one should not perform the lift under these conditions. For making this calculation it is assumed someone has to lift the device 30cm vertically (lift from the ground), 20cm at front of the body and the device has to be carried under and 15˚ angle (from one hand to the other). This results in a start index of 1.53 and an end index of 1.02; this means circumstances are most risky at the start of the lifting action and less in the end. This index corresponds with a recommended max. weight of 13,0kg at the start (picking up the load) and 19,6kg at the end situation (holding the load). Because the user of the SMDLP vehicle does not have to lift the device frequently health risks are minimal, and it may be concluded it is possible to carry a 20kg SMDLP vehicle upstairs. One should also note 23kg is the maximum recommended load under ideal circumstances in the NIOSH-method.

When going downstairs with the folded SMDLP vehicle it is quite likely someone will push it at front; letting gravity do most of the work, because the wheels will roll down by themselves. The user only has to control the speed and prevent the device smashing anything. The reverse is also possible when going upstairs; one might drag the device along when going upstairs, and probably the user is walking backwards in this situation.

14.8. Power input

If we take a more thorough look at the possible user's power input and the speed outcome, a conclusion about efficiency can be made. An average cyclist can produce a power of 100W continuously without getting tired. When riding a 'normal' bicycle this will result in a speed of 18 km/h (5,0 m/s). For a shorter period of time (several minutes) a cyclist can produce a power of 250W. A P95 Dutch male weights 102kg and with an additional load of goods (7,5kg) and the weight of the device (16kg) this results into a total weight of 125,5kg. To gain a more specific insight into the reachable speed and the necessary power input, the following formula is used:

$P_{total} = R_{total} \cdot v / \eta$, **with $R_{total} = R_{air} + R_{roll} + R_{accel} + R_{hill}$**

Speed (v) = 5,0 m/s
Efficiency (η) = 0,95

Air resistance (R_{air}) = $0{,}5 \cdot \rho_{air} \cdot Cw \cdot A \cdot v^2$	$= 0{,}5 \cdot 1{,}23 \cdot 1{,}1 \cdot 0{,}75 \cdot 5{,}0^2$	= 12,68 N
Air density (ρ_{air}) = 1,23 kg/m^3		
Aerodynamic coefficient (Cw) = 1,1		
Frontal surface (A) = 0,75m^2		
Speed (v) = 5,0 m/s		
Rolling resistance (R_{roll}) = $m \cdot g \cdot C_{roll}$	$= 125{,}5 \cdot 9{,}81 \cdot 0{,}005$	= 6,16 N
Mass (m) = 125,5 kg		
Gravity (g) = 9,81 N/kg		
Rolling coefficient (C_{roll}) = 0,005		
Acceleration resistance (R_{accel}) = $m \cdot a$	$= 125{,}5 \cdot 0{,}0$	= 0,00 N
Mass (m) = 125,5 kg		
Acceleration (a) = 0,0 m/s^2		
Hill resistance (R_{hill}) = $m \cdot g \cdot \sin\alpha$	$= 125{,}5 \cdot 9{,}81 \cdot \sin 0$	= 0,00 N
Mass (m) = 125,5 kg		
Gravity (g) = 9,81 N/kg		
Hill angle (α) = 0 °		
So the total resistance (R_{total})	= 12,68 + 6,16 + 0,00 + 0,00	= 18,84 N
And the power input (P_{total})	= 18,84 . 5,0 / 0,95	= **99 W**

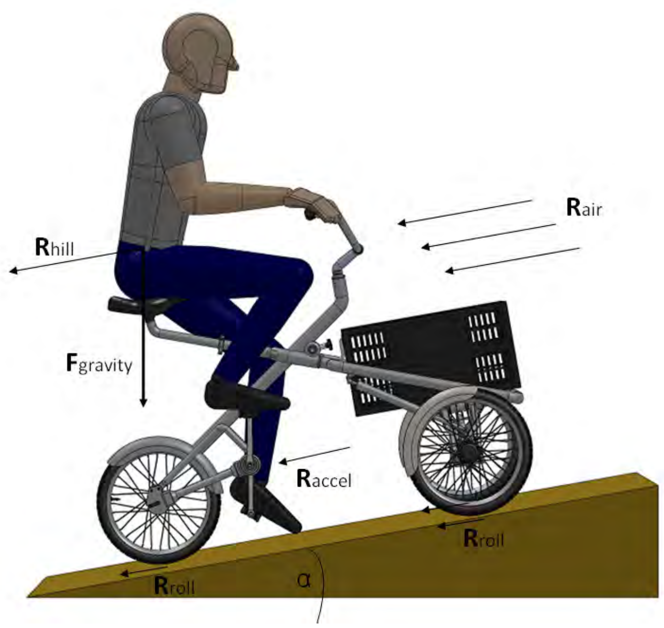
But when the same person is riding a 5 degree uphill road with the same speed the cyclist must produce a power of:

$P_{total} = R_{total} \cdot v / \eta$, **with $R_{total} = R_{air} + R_{roll} + R_{accel} + R_{hill}$**

Speed (v) = 5,0 m/s
Efficiency (η) = 0,95

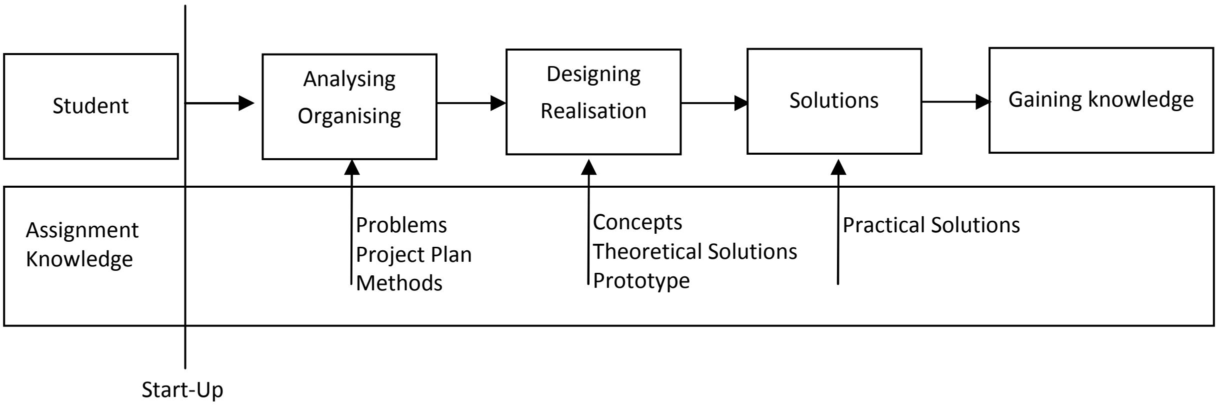
Air resistance (R_{air}) = $0{,}5 \cdot \rho_{air} \cdot Cw \cdot A \cdot v^2$	$= 0{,}5 \cdot 1{,}23 \cdot 1{,}1 \cdot 0{,}75 \cdot 5{,}0^2$	= 12,68 N
Air density (ρ_{air}) = 1,23 kg/m^3		
Aerodynamic coefficient (Cw) = 1,1		
Frontal surface (A) = 0,75m^2		
Speed (v) = 5,0 m/s		
Rolling resistance (R_{roll}) = $m \cdot g \cdot C_{roll}$	$= 125{,}5 \cdot 9{,}81 \cdot 0{,}005$	= 6,16 N
Mass (m) = 125,5 kg		
Gravity (g) = 9,81 N/kg		
Rolling coefficient (C_{roll}) = 0,005		
Acceleration resistance (R_{accel}) = $m \cdot a$	$= 125{,}5 \cdot 0{,}0$	= 0,00 N
Mass (m) = 125,5 kg		
Acceleration (a) = 0,0 m/s^2		
Hill resistance (R_{hill}) = $m \cdot g \cdot \sin\alpha$	$= 125{,}5 \cdot 9{,}81 \cdot \sin 5$	= 107,36 N
Mass (m) = 125,5 kg		
Gravity (g) = 9,81 N/kg		
Hill angle (α) = 5 °		
So the total resistance (R_{total})	= 12,68 + 6,16 + 0,00 + 107,36	= 126,20 N
And the power input (P_{total})	= 126,20 . 5,0 / 0,95	**= 664 W**

From this calculation one may conclude that it is impossible to ride a 5 degree hill with a speed of 18km/h. The necessary power (664W) is way more (414W) than the possible producible 250W. The maximum power input of 250W can be taken as a standard; when a 102kg rider wants to ride a bridge for instance with a 5 degree hilling, the rider’s speed will be reduced to 7,0 km/h (1,94 m/s). With this reduced speed the cyclist has to produce a power of 235W, which is possible.



15. Prototyping

The “Stand-by Mobility Device for Local Purposes” (SMDLP) project has reached a point where solutions in theory have to become reality. In earlier stages of this project analysis where made, problems were tackled and a final concept design was proposed.



In the above presented diagram one can see the design project in abstract. This very diagram makes clear that there is a big difference between a “design” and a “solution”, this because there is a difference between what is possible in theory and what is possible in practice.

A method to prove that solutions are possible not only in theory but also in practice is prototyping. When building a physical model, for instance, more understanding about working principals, production methods, cost price, etc. can be gained. On the other hand a finished prototype is useful to validate the design; this can be done by user feedback and strength tests.

15.1. Plan of execution

15.1.1. Prototype reason

The main reason for building this prototype is to test whether it is possible to create a physical model with the same functionalities and performances as the earlier made CAD model (which can be defined as a virtual prototype). CAD SolidWorks 2009 software was used during the design process in order to develop a concept; downsides of this software are: 1) real physics like gravity and other forces are missing, 2) parts have too much ‘freedom’ because they can move trough each other and 3) the linkage, also called “mates”, between parts do not always match reality.

Another reason for making a physical model is to validate the concept on the hand of user experiences. With a full function prototype users can make statements about function, comfort, reach-ability, effort, appearance, safety, etc.

In this case only the shopping configuration will get prototyped. This because there are many uncertainties about this shopping mode and it is unknown how people will interact with the device. This will be explained more in detail at the “method” section below.

15.1.2. Prototype goal

The main/final goal of this prototyping process is to gain knowledge in order to improve the final product. The prototype can be seen as a kind of trail-and-error process, this will bring forward all kind of experiences. With that gained knowledge it will become possible to advise the company in further product development, and propose recommendations.

15.1.3. Prototype research questions

Main question:

• Is de SMDLP efficient in use at a supermarket *(walking mode)*?

To be able to answer this "main question" it should be divided into some sub-questions that are easier to test separately. Each sub-question is related to a separate test section; which has its own parameters and independent outcome.

Whether the SMDLP is efficient in use at the supermarket is strongly related with the (driving) character of the prototype and how people can interact with it. So in fact, I want to test the influence of parameters like: 1) steering height, 2) crate height and 3) turning radius on usability (user experiences).

Sub-questions:

• Is the proposed (120 cm) steering height sufficient?

• Is the proposed (… cm) crate height sufficient?

• Is the proposed (2.6m) turning radius sufficient?

15.1.4. User research method

In order to answer all the above described 'research questions' a <u>virtual model</u> and full scale functioning <u>physical model</u> of the walking mode (shopping configuration) will be build. This because there seems to be a trade-off between creating a fully physical imitation of the concept and only making the most needed physical, where other issues can be tested virtually. A fully functioning on scale physical prototype, which contains all three configurations, was considered to be too expensive and time consuming. Therefore it is preferable to only make the shopping-configuration physical in order to do a user research.

This shopping configuration is most valuable (in comparison with the riding mode and stand-by mode) in its physical form because it contains most uncertainties in relation with both user experiences and functional-related performances. Another reason to do this is the shortcoming of helpful data and literature about this item. On the other hand there is information available that can be related with the riding and stand-by configuration. For instance ergonomically data about cycling postures and measurements of other folding cycles can be used for comparisons. In addition, the stand-by mode does not request much user interaction and therefore it is not meaningful at this very moment to create a physical prototype of it. How to find answers about the above described research questions will now be explained.

The research questions are mainly related with user experiences about the SMDLP in walking mode during supermarket visiting. Therefore a physical prototype will be build (the design will be explained in the next paragraph); this prototype will get tested by 4 pre-selected participants with diverging body height and gender.

The test location will be the Super de Boer supermarket at Stationsweg 44 in Leiden. This supermarket is situated right in front of the Leiden central station and is a typical crowed inner city supermarket. Participants are asked to do some shoppings (collect items from a pre-processed shopping list) and they will use the prototype to accomplish their task.

The user test begins at the supermarket entrance where the participant is handed the prototype and the shopping list. The shopping list ensures a certain amount of shoppings, and a minimal walking route inside the supermarket (participants have to gather at least potatoes, bottle of soda drink, canned tomatoes, ice-cream and bread). Beside the diversity in weight, the items have to be collected from different shelf heights and types. How a participant collects and places the item into the shopping cart will get market in a postures diagram.

When all shoppings are gathered it is time to go to the cash desk. Participants may use the do-it-yourself cash desk or go to a cashier (both situations should be video filmed when possible, at least when both options are available at the Super de Boer store). In this last phase of the user research, participants are asked to put their shoppings onto the conveyor-belt, pay and recollect their items inside the shopping cart.

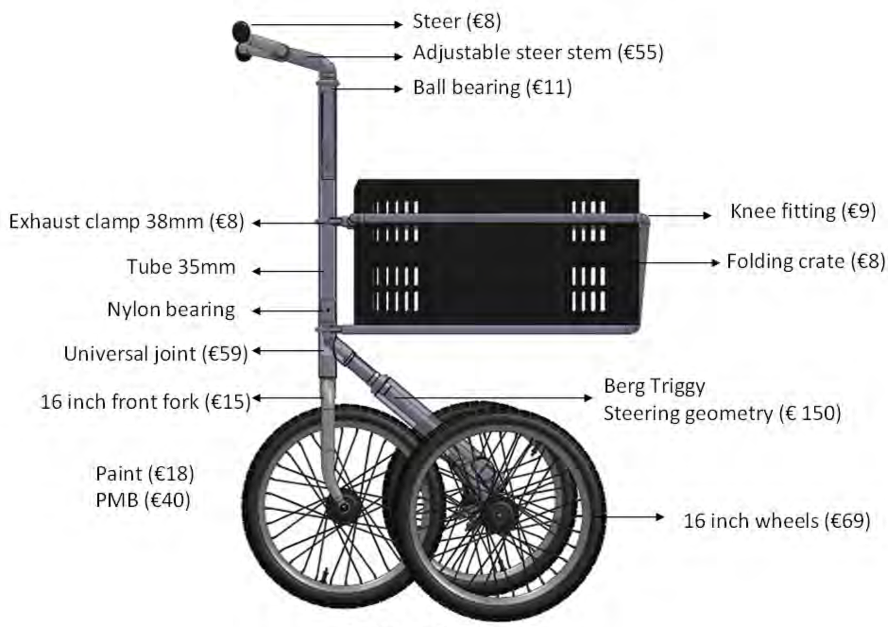
(When problems arise in reach-ability of the prototype, photographs will be taken of obstacles or other limiting situations).

15.2. Prototype design

A prototype was made in order to asses the use of the product. Within time limits, and considering the costs, it was not possible to come up with a fully physical prototype with all functions embedded in it.

First of all it is very important to notice there are some differences between the final design of the product and the prototype. In a function-orientated prototype, appearance is not so important and will be eliminated when causing troubles with financial-, production- and performance-aspects.

In fact the prototype is a simplified version of the product design, basically meant to test the implemented working principals and the associated dimensions. In that occasion the CAD model of the product's overall design will be transformed into an easier to produce, and therefore cheaper model. The idea is to simplify individual parts by eliminating form-giving, choose alternative materials and use other production methods.



As you can see in the above standing picture, the prototype design is merely made out of standardised parts. The steering geometry is adopted from a Berg Triggy 3-wheeler skelter, the steering assembly and rear wheel suspension are bicycle parts. I mounted 16inch wheels onto the steering geometry and created a frame of steel tube that are welded together. The steer is connected with the skelter's steering geometry by use of a universal joint; so the movement of the steer can be transported to the front wheels. I also made a wire frame that holds the basket on its place, this is connected to the main frame by use of exhaust clamps.

15.3. Prototype building

Taking the CAD SolidWorks model of the prototype as a starting point, parts have to be indicated whether they are purchasable as standardised parts or whether they have to be made. To do so the required parts will be sourced at supplier websites and catalogues. Non purchasable parts have to be produced; price request and ability to produce is required from potential supplier.


After all parts are bought/made and supplied the assembling of the prototype begins. When possible parts are pre-assembled at the supplier's location, if not further assembling can take place at the PMB-IO. In the workshop of the TU Delft Industrial Design faculty it is possible to tap treat to create bolt-nut connections and weld metal parts together. With help of the PMB I was able to build the prototype as planned as you can see in the pictures above.

15.4. Prototype usability test

A usability test at the supermarket is executed as described in section "15.1.4. User research method". The most relevant outcome of this test will be discussed here, for all result please take a look at the appendix *[Appendix XI; Prototype usability test]*.

Whether the proposed steering height of 120cm is sufficient is researched; participants had to perform some tasks in order to validate the steering height. None of the participants found the pre-set steering height of 120cm was limiting in usage of the shopping cart. This means all participants were able to steer at a 120cm height, although their average preferred steering height was 108cm. It is remarkable that the longest test person (body height 178cm) preferred the lowest (104cm) steering height and the shortest participant (body height 161cm) set the steer to the highest (114cm) preferred steering height. In all occasions participants prefer the steering height to be lower (average steer height 108cm) than the proposed (120cm) height.

In usage, and mainly during collecting items and loading these into the shopping basket of the test cart, participants bend over the steer to put items inside the basket. In 55% of the counted approaches participants positioned themselves at the back of the cart. While holding the steer, people reached over it in order to put shoppings inside the basket. Apparently the steer was not too high in order to do this. An alternative is approaching sideways, 35% of the counted approaches where executed in this way. In only 10% of the occasions the cart was approached at the front.

Put shopping in basket: approach

Approach side (35%)

Approach front (10%)

Approach back (55%)

From the fact that the steer (set at 120cm) was not blocking this behaviour and none of the participants experienced difficulties while steering at this height, it can be concluded that the *proposed steering height of 120cm is sufficient*.

Whether the proposed crate height is sufficient is researched in a similar way; participants were asked to collect items and bring them to the cash desk, later they were asked about their experiences. The crate height is relevant while loading gathered items from the shells into the basket, but also when unloading and reloading at the cash desk.

Put shopping in basket: posture

Bend; 1 arm loads (85%)

Bend; 2 arms load (10%)

Bend and twisted (5%)

Most items were put inside the basket one handed; 85% of the items were put inside the basket with this posture. Merely heavier items were placed inside the basket with two hands, this only occurred at 10% of the time shopping were gathered. A bend and twisted posture is quite seldom and only occurred at 5% of the occasions. A "2 arms load" posture requires a deeper bend of the participant as you can see in the pictures above. When only using one arm to put an item inside the basket a participants puts his weight on one foot and tilts forward, resulting in a more up straight posture. The way people bend over and the degree of bending is observed in four categories; 1) straight; 0˚ bend, 2) slightly bending; 30˚ bend, 3) heavily bending; 60˚ bend and 4) totally bending; 90˚ bend. All people had to bend in order to put the items inside the basket (in one occasion a participant throws bread inside the basket, but already slightly bend forward), but only category 2 and 3 were observed. Category 4, which means someone has tot bend forward totally (spine in horizontal 90˚ position with respect to the vertical) is frequently present when using a conventional shopping cart or a wheeled basket. Participants mention that they need to bend over so much when using a conventional shopping cart because of its basket depth. When using a wheeled shopping basket people have to bend over totally all the time because it is standing onto the ground permanently.

When unloading the collected items at the cash desk, none of the participants complained about the crate height. Participants showed different positions while unloading; they were standing at the back of the test cart, but also at the side and front. The items went over the conveyor belt and the participants did put back the items inside the basket. All participants were standing at the back of the shopping cart, and some of them moved in between the cart and the cash desk. In the test evaluation participants state that it was quite easy to load and unload, because the crate is located high enough and one does not have to reach so deep inside the basket in comparison with a conventional shopping cart.

From the fact that people did not have to bend forward as much as with the alternatives (conventional shopping cart and wheeled shopping basket) and only bending forward to 60˚ maximum was observed it can be concluded that the *proposed crate height is sufficient*.

Whether the proposed 2.6m turning radius is sufficient can be validated when taking a closer look at usage situations in which turning around, bouncing and abandoning occurs. During the usability test it became clear that participants were unable to turn the prototype shopping cart around in a shopping path with one single turning movement. The turning radius of 2.6m is simply bigger than a shopping path's width; therefore people found other options in order to turn around, see appendix *[Appendix XI; Prototype usability test]*.

Turning around

The way the cart steers and turns made participants bounce upon several object, and mainly difficulties in steering made people decide to abandon the shopping cart in order to collect the requested items. Participants had difficulties in steering this alternative shopping cart, because it reacts totally different than a conventional shopping cart. The steering mechanism of the prototype can be compared with the steering of a car. This means when driving forward steering movement is similar to the direction, but when driving backward one needs to counter steer because the steering mechanism works the other way around. Participants did not expect this to happen, causing the bouncing and abandoning behaviour at first. During the test participants learned how to handle the cart and its way of steering, in the video film one can see mayor improvements in steering.

From the fact that participants were unable to turn around in a shopping path with one single steering movement in combination with the bouncing and abandoning behaviour, it should be concluded that the *proposed turning radius is not sufficient*. But people show mayor progress in steering and found out other options in order to turn around. Therefore it should be considered whether the way of steering should be redesigned or whether it is normal for people to learn at first, and get used to the way a new product acts.

15.5. Prototype conclusions

•The proposed steering height of 120cm is sufficient because: none of the participants found this height was limiting in usage (steering) and in 55% of the counted approaches participants were able to bend over the steer in order to put shoppings inside the basket.

• The proposed crate height of …cm is sufficient because: people did not have to bend forward as much as with the alternatives (conventional shopping cart and wheeled shopping basket) and only bending forward to 60˚ maximum was observed.

• The proposed turning radius of 2.6m is not sufficient because: it is not possible to turn around in a shopping path with one single steering movement and the way of steering make people bounce and abandon the shopping cart.

16. Rendering

In the following two pictures the finalised concept is displayed by renderings of the SolidWorks model. It was decided to present a ´neutral´, 'pure aluminium' version; so there is no colour coating or any other brand/supermarket related expressions on it. Of course that can be added later, when there is a participating bicycle manufacturer or supermarket involved. Renderings of the SMDLP show an image of a quite stylish mobility product, with a strong product identity. The X-shaped frame is the most eye-catching in this, and the design of the other frame parts made the crate and shaft drive integrate nicely. The foldable crate is 'embraced' by the 'arms' of the front part of the frame, holding your shoppings safely. The use of difference tube diameter and the way they were bend, plus the decision to make a bend in the seat tube in combination with the 'ape-hanger' steer type, result in a playful appearance.

17. Recommendations

In the following a set of recommendations will be provided to the company, these recommendations could be taken in consideration when continuing the development process of SMDLP concept. Despite my best effort to cover every aspect of the new product, I realize there are certain areas where the company could improve the product a little further. Hence, the purpose of this recommendation is to give the company some further suggestions regarding the 'product' and on 'strategy' which can be improved after this graduation project. In the following some recommendations based on concept improvements (product), and after that some recommendations about an alternative marketing plan; payment and rental system (strategy) will be given.

17.1. Concept improvements

First of all, in this graduation project the SMDLP concept is validated with help of a virtual SolidWorks model and the walking mode was also prototyped. The prototype was very valuable for testing people's abilities when cooping with the product. Executing a similar process for testing the riding mode is strongly recommended. A full scale, fully functioning prototype that enhances all three configurations could provide an insight in how people interact with the product in real life and what difficulties there are.

The same prototype could be used to conduct a consumer research to evaluate the ergonomic aspects of the SMDLP. The user's posture while riding the SMDLP vehicle is validated in SolidWorks only, but in real life research participants could give valuable feedback about their experiences as well. Participants diverging in body length could be positioned onto the prototype and the range in adjustability (per adjustable part) could be determined. While doing this the level of comfort could be linked onto body length, riding posture, vehicle geometry and how people experience riding the vehicle could be evaluated.

The stand-by mode contains some other ergonomics issues that require further investigation. It should be investigated whether people are able to fold and unfold the SMDLP and whether the use cues that are implemented are understandable. This could also be researched with help of the full scale, fully functioning prototype. Speaking about these use cues; mechanisms like the hinges and the fixating rotary and push buttons could be integrated more in the design. These parts need further elaboration and detailing.

Another very important recommendation is to conduct a reliability analysis of the SMDLP concept to investigate which parts are most likely to fail during use. A static strength analysis of the frame has been executed in this graduation project, but when detailing the product such strength analyses have to be executed per part.

The strength of the frame is validated with help of a Finite Element Method (FEM) analysis in SolidWorks, and shows bending of the seat tube and main tube could be an issue. It is recommended to investigate whether it is possible to strengthen the frame by adjusting the geometry slightly or select alternative materials. It is also recommended to execute a real life strength test by applying forces onto a physical model (could be the prototype) and see which parts fail the first and whether this is acceptable.

When there are major issues with the X-frame geometry in terms of strength and difficulties with implementing cable steering for instance, it is recommended to investigate whether another (more conservative) frame geometry could be the better solution. In this graduation project I chose for a distinguishing design by implementing the X-frame, resulting in a very strong product identity but lack of strength at the seat tube and a relative difficult steering mechanism (cable steering) are a result of this decision. A connection between the seat tube and the main frame may prevent this, but this makes the design aesthetically less attractive.

The final recommendation regarding concept improvement is to improve the aesthetics of the SMDLP by integrating the hinges, buttons, and other joints more in the frame geometry. Shapes of individual parts could make the total design 'melt' more together, resulting in a 'cleaner' and 'smoother' design when speaking about aesthetics.

17.2. Payment and rental system

The SMDLP could be placed into a different perspective when combining the vehicle with a payment and rental system. This subject was investigated for the TU Delft course "Smart System and Technologies", this total assignment is added in the appendix *[Appendix XII; Payment and rental system]*. The main goal of this assignment was to investigate how smart systems and technologies could be used in order to enrich the SMDLP concept in terms of a more 'intelligent' product.

When implementing a payment and rental system, the main idea would be to sale the SMDLPs to the supermarket (guarantees high sale quantities) and implement some sort of customer bonding with help of an 'intelligent' system. In this scenario supermarkets have to invest in purchasing the SMDLPs and in combination with a rental system they can profit from customer loyalty. With this system supermarkets can transform into a new formula where less conventional shopping cart, car parking spaces and bicycle racks are needed. In this manner users can freely make use of the supermarket's SMDLP rental system (no cost of ownership) but are bond onto that one specific supermarket chain when using its transportation mean.

When looking from this perspective one can see the earlier defined design criteria (chapter 6.) could be interpret otherwise. Criteria about fabrication cost price and selling price are less rigorous; for supermarkets it more interesting to know whether it is possible to earn back the investment instead of prices per vehicle. For the user the rental system means an ultimate 'low cost of ownership' and the selling price is not relevant for them anymore. Criteria about the vehicle's weight are also less important because the vehicle will not be stored in home anymore, but will remain in the public space all the time. On the other hand the SMDLP concept should be more vandalism and theft proof when combining it with a payment and rental system.

In this scenario a smartphone is used in both the payment and rental system. In the payment system RFID technology is used to speed up the check outs at the supermarket; the user can ride out of the supermarket and pay for the shopping with a simple blink of the smartphone with and NFC reader. In the rental system GPS, NFC and the smartphone are combined, so people can reserve a SMDLP vehicle and use it freely in a pre-defined zone. A smarthub, cable lock and alarming system are used in order to protect the vehicle against vandalism and theft.

The supermarket is a very important stakeholder in this scenario, but was left out in the initial marketing plan. When selling the SMDLPs directly to the users there is a high risk supermarkets will eject the SMDLPs from their supermarkets because they can not benefit from it in any way. With this insight it is recommended to investigate how to involve (by implementing the payment and rental system for instance) supermarkets in the SMDLP project.

18. Evaluation

18.1. Product evaluation

First of all I would like to mention I am quite pleased with the resulting product proposal of this graduation project. I really believe the Stand-by Mobility Device for Local Purposes has great market opportunities and provides an alternative for supermarket visiting. The design is quite innovative when speaking about combining three configurations into one device, linking indoor and outdoor usage together and implementing a foldable steering mechanism combined with the suspension system, is something I am most proud of.

In the following the proposed product design will be evaluated according to the earlier described design criteria (chapter 6). When the design meets the design criteria, this will not be mentioned explicitly. More interesting to know is whether the design does not meet all requirements, and what is the reason for this. This will be described in detail, so it might be possible to improve the design in the future.

Not achieved norms
In the design criteria section of this report I mentioned some norms that could be relevant for the SMDLP. These norms do describe the necessary safety requirements and test methods for bicycles and luggage carriers in detail, but were not specifically used in this graduation project. This is due to the fact I only had limited access to these norms, and I did not want to limit myself too much in this creative process because of the very detailed, and specific norms. I believe when improving the SMDLP after this graduation project, norms will play a very important role. This graduation project was merely a first exploration of concept possibilities.

Not achieved usage demands
The SMDLP concept does meet most of the requirements relevant for the usage phase, but two of the demands were not explored much enough and two other requirement were not met. First of all I really do not know yet whether users between 14-65 years are able to operate the device. This can only be investigated with an extensive user research. Secondly I stated the device should have a parking position, avoiding it to roll away. The stand-by mode can be considered to be this parking position; in stand-by mode the SMDLP is positioned at a bicycle stand that lifts the rear wheel of the ground, so it could not roll away. In walking and riding mode such a parking or wheel blocking mechanism is missing, but the necessity of such a mechanism should be investigated per usage mode. The two requirements that are not met are both describing the required turning radius of the device. A narrow turning radius of 1-1,5m in walking mode could not be achieved, and therefore it is also impossible to make an 180˚ U-turn in a 2m wide shopping path without lifting the device of the ground. From the user research with the prototype of the walking mode it was concluded people are not able to make such turns, but with a little more effort and turning movements people are able to reach all locations at the supermarket.

Not achieved safety demands
In the SolidWorks model and the prototype parts regarding safety, like lights, reflectors and a bicycle bell were not implemented, and therefore these requirements are not achieved yet. These items can easily be added later; in contrast the SMDLP does meet the Dutch traffic legislation, which also concerns safety.

Not achieved loads demands
The SMDLP's construction should be able to hold 102kg as a maximum body weight of the user, in the FEM analysis it was concluded the structure will hold under this load but the seat tube and main tube will bend slightly. Therefore an additional requirement that describes the maximum deformation is needed, because I believe the deformation as it is now might be too much.

Not achieved wishes
The only wish that really could not be achieved in this graduation project is to limit the device's weight to a maximum of 16kg. Other wishes are achieved or are still al little uncertain and need further exploration.

18.2. Process evaluation

This graduation project has come to an end, and now it might be very useful to evaluate my design process so I can learn from it in the future. In this way, it is my intension to gain knowledge that might be useful for future projects.

The first part of this graduation was executed in cooperation with the Corners and Curves design studio in The Hague. Corners and Curves asked me to start a graduation project at their company about a new bicycle concept; it was mentioned they already had some ideas. When I started this assignment, I came to realise their ideas were very vague and very little was arranged (no connections with bicycle industry, nor there was a defined budget). As a result of this I decided to start an exploratory analysis phase, researching mobility, the market and the potential consumers. I convinced Corners and Curves to create a new mobility concept for supermarket visiting purposes based upon the results of my analysis.

One of my biggest mistakes during this project was the lack in making proper agreements with Corners and Curves about the design direction, the budget, connection with bicycle industry and the commitment of Corners and Curves. Afterward it seemed we thought different about these subjects, and it was quite naïve of me to think everything would work out just fine. As a result of this we disagreed upon some fundamental aspect, and I decided to end the cooperation with Corners and Curves.

In the first place, it would have been better to execute this graduation project at a bicycle design company or manufacturer. I really missed input from such companies; the design space could have been clearer at an earlier stage and the presence of applicable knowledge might have been resulted in a shorter design process.

I did go trough some design loops, trying to come up with an innovative mobility concept by making numerous sketches and computer models. This process took a long time, this is also because at that time it was not clear what the concept should do or look like. In the future I will try to limit this process, and first define the concept in writing before diverging.

I have noticed that I often had the idea, the 'solution' to a specific problem was found, and I did not search any further for alternatives. This 'narrow view' means that a particular working principle is embraced too quickly, leaving no possibility to come back to that decision. So the elaboration of the concept in terms of working principals made me stick with some possible solutions in principal, this is also know as 'clamping'. The found solution is considered to be the only solution, and alternatives are not well enough explored. I found deciding which sub-solution might be the best is quite difficult to do, and this leaded to 'postponing decisions', resulting in delays.

When I started this graduation project I did not know much about designing bicycles, or any other mobility concept. I continuously felt I had too little specific 'bicycle' knowledge, and this lack of knowledge made me struggle with finding proper solutions. But during this project I learned a lot; about working principles that could be implemented, frame geometry and the ergonomic aspects involved.

During this design process I tried to 'structure' the work, by writing a "Project (design) plan". This describes the strategy and methods that were used; this was my guideline during this process. I believe my work is executed in a structured way, and I was able to show my design skills in this graduation project while covering most of the design aspects.

At last, I realise I have to improve my communicative skills. It is very important to keep other 'participants' like the company and the supervisory team up-to-date, otherwise a loss in interest is the consequence. I want to apologise myself for the lack of communication towards the supervisory team (Bas Flipsen and Anton Jellema) and I promise I will do better in the future.

I want to end this evaluation with special thanks to Bas Flipsen and Anton Jellema for your guidance, input and patience.

References

Belch, 2004; G. E., & Belch, M. A. Advertising and Promotion: An Integrated Marketing Communications Perspective

Bikefitting, 2008; Bicycle fitting systems and measurement methods, www.bikefitting.com

CBS, 2008; Centraal Bureau voor de Statistiek, www.cbs.nl
- *Fietsen naar het werk populair bij kleine afstanden.*
- *Vier op tien Nederlanders heeft last van verkeer*
- *Cumulatieve bereikbaarheid*

Dined, 2004; Dined Human Anthropometry Database, www.dined.nl

EC, 2007; European Commission, http://ec.europa.eu/transport/urban/urban_mobility/green_paper/doc/2007_09_25_gp_urban_mobility_memo_en.pdf
- *Towards a new culture for urban mobility*

Exploratorium, 2008; Science of Cycling, www.exploratorium.edu/cycling

Handy, 1994; *Highway Blues: Nothing a Little Accessibility Can't Cure*. Access, No. 5, pp. 3-7.

Handy, 2002; *Accessibility vs. Mobility; Enhancing strategies for addressing automobile dependence in the U.S.*, http://www.des.ucdavis.edu/faculty/handy/ECMT_report.pdf

Harms et al., 2005; Harms, L., Need, Y. and Boumans, A., http://www.cvs-congres.nl/cvspdfdocs/cvs05_68.pdf
- *De beleving van mobiliteit, een onderzoek naar subjectieve aspecten van verplaatsingsgedrag*

Hult, 1992; The Itera Plastic Bicycle, http://sss.sagepub.com/cgi/content/abstract/22/2/373

Hoyt, 1939; *The Structure and Growth of Residential Neighbourhoods in American Cities*, Washington, Federal Housing Administration

IHT, 2008; International Herald Tribune, www.iht.com
- *UN says half the world's population will live in urban areas by end of 2008*

NationMaster, 2008; World statistics – country comparisons, www.nationmaster.com
- *Dutch People Statistics*

Pheasant, 1996; Bodyspace*, Anthropometry, Ergonomics and the Design of Work, 2nd edition, Taylor and Francis, London.*

Ruimtemonitor, 2008; Planbureau voor de Leefomgeving, www.ruimtemonitor.nl

Stichting Velofilie, 2008; Technische artikelen over de fiets, www.velofilie.nl
- *Vermogen*
- *Rolweerstand*

SdB, 2009; Super de Boer supermarkets, conversation with region manager

WBCSD, 2001; World Business Council for Sustainable Development, www.wbcsd.org
- *World mobility at the end of the twentieth century and its sustainability*

Wikipedia, 2008; Wikipedia – The Free Encyclopaedia, www.wikipedia.org
- *Hoyt sector model*
- *Urbanization*
- *Sustainable transport*

Appendix

Appendix I; *Internet questionnaire about supermarket visiting*

In the following five questions about supermarket visiting in relation with transportation means are displayed. Please fill in the open-questions and mark your answer, making use of the (O) circular answer boxes.

Name	
Age	
Address	

1) What is the location of your primary supermarket?					
Supermarket	Albert Heijn	Hoogvliet	Aldi	C1000	Other
	O	O	O	O	…
Address					

2) How often per week do you visit a supermarket?			
Less than ones a week	2-3 times a week	4-5 times a week	Almost every day
O	O	O	O

3) How do you travel between home and supermarket?			
With the car	With a bicycle	Walking	Other
O	O	O	…

4a) I believe supermarket visiting with a <u>car</u> is:					
	Highly disagree	Disagree	Neutral	Agree	Highly agree
Comfortable	O	O	O	O	O
Irritation free	O	O	O	O	O
Relax	O	O	O	O	O
Affordable	O	O	O	O	O
Pleasant	O	O	O	O	O
Fast	O	O	O	O	O
Flexible	O	O	O	O	O
Effortless	O	O	O	O	O

4a) I believe supermarket visiting with a <u>bicycle</u> is:					
	Highly disagree	Disagree	Neutral	Agree	Highly agree
Comfortable	O	O	O	O	O
Irritation free	O	O	O	O	O
Relax	O	O	O	O	O
Affordable	O	O	O	O	O
Pleasant	O	O	O	O	O
Fast	O	O	O	O	O
Flexible	O	O	O	O	O
Effortless	O	O	O	O	O

4a) I believe <u>walking</u> to a supermarket for visiting is:					
	Highly disagree	Disagree	Neutral	Agree	Highly agree
Comfortable	O	O	O	O	O
Irritation free	O	O	O	O	O
Relax	O	O	O	O	O
Affordable	O	O	O	O	O
Pleasant	O	O	O	O	O
Fast	O	O	O	O	O
Flexible	O	O	O	O	O
Effortless	O	O	O	O	O

5) Last time I went to the supermarket by *[car / bicycle / walking]* and bought …… kg of shoppings (please use a scale to determine the mass of your shoppings).

Appendix II; *Details of existing products*

Bicycles

EMS E+ Mountain bike | Beixo SLIM | PUMA glow rider | ORMAZD | Helkama 101i

EMS introduces a 750 Watt electric assist motor in a sports vehicle, resulting in the E+ mountain bike. This way of thinking about sports is quite new, because motor assistance in sports might seem to be contradicting. However for sports on a recreationist level this might be a perfect solution; providing less skilled people the ability to climb higher mountains and ride more difficult routes. *[www.e-ms.us]*. In the second picture the Beixo SLIM is shown; main selling point is to get rid of the greasy chain. To do so Beixo uses an innovative shaft drive system, familiar as a cardan drive. *[www.beixo.nl].* Shaft driven bicycles were invented late 19th century and were extremely popular because there was no danger for the wide clothes ending up in the chain. Due to the impossibility to use gears the system was supplanted by chain-driven bikes. Nowadays, because of modern production techniques, it's no longer a problem to use a shaft drive system in combination with gears. Therefore all advantages of the shaft drive technique (clean, low maintenance and save) can be used again. Also the lemon green ORMAZD.paz, which is made by the Taiwanese Fullness Group, is a shaft drive bicycle. Most remarkable of this bike is its U-shape aluminium alloy frame. In the middle the orange PUMA glow rider is displayed, which is the third edition of the PUMA bike. *[um.puma.com]*. The new model distinguishes itself through the unique glow in the dark frame. The night glow effect paint used on the steel frame of the bike collects the sunrays during the day, and gives this light off when darkness has fallen, lasting for several hours. The glow in the dark idea improves the rides safety by making the whole bike more visible, but also makes a statement for aesthetics during the night. The Helkama 101i is outstanding because of its frame, made out of high-pressure cast magnesium, which is both strong and ultra light weight. Due to the patented hollow frame, it was possible to hide the cabling system, making the end result both functional and stylish. *[velosport.fi].*

Folding bikes

Mobiky | Strida | Brompton | Giant | Dahon | Birdy | GoBike

The Mobiky is a very compact folding bicycle, which folds intuitively and fast. The Mobiky is designed for instant usage, and meant to cover only just a few kilometres from home to a station for instance. *[www.mobikyusa.com].* Another very popular folding bike is the Strida; this bike is very ingenious because of its way of folding, belt drive and frame structure. The Strida is a single gear with (dry) belt drive, which means no shifter or greasy chain, no tension adjustments and no caught pant legs. The A-shape frame has an integrated saddle and handle-bar, and is very solid because of its triangular shape. The bike has a very tight turning radius, enabling to manoeuvre in traffic quite easily. One of the most important features of Strida is the fact that it can easily be rolled when folded and its lightweight of 10 kg only. *[www.strida.com].* Brompton on the other hand seems to be more robust and agile, but is a full-sized bike. Brompton provides a high riding comport, although the bicycle folds in a small package which carries like a small suitcase. *[www.brompton.co.uk].* A solid frame is, like Brompton, also one of the main selling points of bicycle manufacturer Giant. Its Giant Halfway just folds in the half, and the one sided front and back forks allow a flatter fold. The Giant Halfway has 6 speed gears and detachable carrier tools to enable people to bring additional stuff along. *[www.giant-bicycles.com].* A folding bike is meant to be the link between mobility devices, like car and train for instance. Most folding bikes therefore fit inside a cars trunk and can be brought along in trains. The Dahon Curve is one of those bikes that is made for squeezing onto crowded trains and buses on your commute, or as secondary transport stashed in your car. *[www.dahon.com].*

Something new in the folding bikes category is a remarkable front suspension system, as one can see in the Birdy and GoBike. *[www.birdybike.com] and [www.gobikeworld.com].* The idea behind it is to be a full suspension folding bike, where the pivot point of the suspension will also serve as the folding joint. Integrating folding functions with other bicycle function may reduce both the amount of parts and amount of user actions, resulting in a faster and more pleasant usage. So there are many different folding bikes, with different functions, designs, and geometries. One clever thing of GoBike is the fact that they used many standardised parts which means parts are available everywhere around the world and can be repaired by any reputable bike shop.

Alternative gearing

Unicycle | SQRL | Scooby | PumGo scooter | Trikke | Pulse Kick 'N Go | Batavus Bike Stepper

The Unicycle is a very minimalist transportation device, which also contains a fun element. A person has to be ‘skilled’ in order to stay in balance. When looking at the products with alternative gearing, it is quite obvious that some practice is required, and only skilled people are able to ride such vehicles. The SQRL *[www.takeitout.co.uk]* and Scooby are a parody to the unicycle, although they have two wheels. One wheel is for pedalling and the other is for steering reasons. Even like a unicycle the rider has to be trained to remain stable. One can steer the SQRL around when making hip movements, the Scooby has an handlebar for steering but has no seat. Another category are the scooters, like the PumGo, Trikke and Pulse. These scooters can be driven by stepping, shifting or kicking a single pedal. The PumGo scooter is a very compact scooter, which goes forward by making a very small step movement. *[www.pumgo.com].* The Trikke provides a stable 3-point platform that leans into the turn with the rider while all three wheels remain in contact with the ground. A rider may reach speeds of up to 18 mph on flat ground, ride 50 miles in one day, and climb the steepest of hills (with practice!). *[trikkescooters.net].* Unlike traditional scooters that require constant pushing off the ground, the Pulse Kick 'N Go uses a unique chain and kick pedal self-propulsion system, allowing the rider to achieve blazing speed and tight manoeuvrability while maintaining a balanced stance on the deck. *[www.pulsekickngo.com].* A more conventional concept is the Batavus Bike Stepper, which in fact is a bicycle that uses stepping movement instead of a pedalling movement. The Batavus Bike Stepper can be compared with a fitness Crosstrainer or a Moonwalker, but with wheels on it. The wooden footboards are used to get traction onto the chain drive, which makes the back wheel spin. The input motion is similar to a Crosstrainer, kicking the footboards down in anti-phase. The concept has seven gears allowing different training levels, while enjoining being outside. *[www.batavus.nl].*

Electric powered

E-bike | E-Bikeboard | Toyota Winglet | Segway | Yamaha Bobby

The E-bike is a, in this case foldable, motorised bicycle whereby the motor assist with pedalling. Some early motorized bicycles were powered by internal combustion engines whereas some utilised electric motors. With lighter batteries and better storage density, the electric motor has recently seen an increase in popularity. Motorized bicycles are distinguished from motorcycles by being capable of being powered by pedals alone if required. The actual usage of the pedals varies widely according to the type of vehicle. Those known as mopeds mostly have pedals for emergency use or because of legal requirements and these are not normally used. Those known as power-assist bikes have the pedals as the main form of propulsion with the motor used to give a bit of extra speed, especially uphill. The E-Bikeboard is a variation onto the ‘normal’ E-bike, and is a 3-

wheeled, head-turning, versatile electric scooter that allows the rider to experience a unique carving sensation while riding it. It is ecologically friendly as it is motorized by an electric hub engine which is powered by Lithium Polymer rechargeable batteries. It runs silently, has zero emissions and is capable of reaching a maximum speed of 25 kilometre/hour with a range of 50 kilometre per 2 battery charges. *[bikeboard.com].* The Winglet is another electronic concept made by Toyota, and consists of a body (with a projected area the size of an A3 sheet of paper) that houses an electric motor, two wheels and internal sensors that constantly monitor the user's position and make adjustments in power to ensure stability. Meanwhile, a unique parallel link mechanism allows the rider to go forward, backward and turn simply by shifting body weight, making the vehicle safe and useful even in tight spaces or crowded environments. *[www.toyota.com].* The Segway is a two-wheeled, self-balancing electric vehicle. Computers and motors in the base of the device keep the Segway upright when powered on with balancing enabled. Users lean forward to go forward, lean back to go backward, and turn by using a "Lean Steer" handlebar, leaning it left or right. Segways are driven by electric motors at up to 20 kilometres per hour. Gyroscopic sensors are used to detect tilting of the device which indicates a departure from perfect balance. Motors driving the wheels are commanded as needed to bring the Segway back into balance. *[www.segway.com].* The Yamaha Bobby is an electric commuter vehicle that is equipped with a variety of Internet services that make sure you are always connected, even when riding the bike. You can turn it on or off simply by holding up a FeliCa-enabled cellphone to the switch. Other interesting features include a collapsible seat, a fold-in rear wheel, handlebars and footrests for easy and expedient storage. *[www.yahama.com].*

Carrier cycles

Taga is a multifunctional urban vehicle, uniquely designed to suit the needs of today's parents and children. Taga combines the benefits of a premium stroller and a carrier bicycle to create a new transportation modality. Taga lets parents and kids move about the city easily. When reaching the desired destination, whether a shop, cafe, indoor playground or a friend's house, Taga is converted within seconds into a stroller allowing, parent and child to conveniently enter the premises, ride an elevator or ascend steps. There is no need to lock Taga outside and no parts are left behind. Taga can also be taken on the underground, train, bus or any other means of public transportation, offering continuous riding to and from any destination. *[www.taga.nl].* TrioBike is the world's first family carrier bike with 3 independent functions: a bike, 2-seat buggy and multi award winning carrier bike. Simple interchangeable design requires no tools to switch between functions. Capable of carrying 80kg payload equivalent to 2 children aged up to 9 years. The TrioBike has 5 point safety belts for the children, disc brakes, integrated front- and rear lights, fireproof hood and seats, that also have been tested for heavy metals. *[www.triobike.co.uk].* The Gazelle Cabby is an alternative for the three-wheeled carrier cycle. The Cabby includes a slim design with seven gears, rollerbrakes, cooling disks and a hub dynamo. The Cabby is suitable for transporting an adult and two kids. The cargo compartment provides two belted seats, but is also suitable for placing shoppings or a Maxi-Cosi baby carrier instead. *[www.gazelle.nl].* The Babboe Big is a more conventional carrier cycle at first sight, this redesign is much saver, stronger and cheaper. The price is the main selling point of this concept. Babboe sells its cycles via Internet directly to the costumers and people have to assemble the bike themselves, resulting in a lower price.*[www.babboe.nl].* The Zigo is a modular family transportation system, enabling three configurations; biking strolling and cycling with the stroller attached. There are two seats for the children inside the ChildPod, and one parent can ride the bike. The LeaderLink System allows the parent to uncouple in 30 seconds or less, transforming it into the separate elements, Zigo ChildPod and Zigo Cycle. *[myzigo.com].*

Appendix III; *Details of inspiring products*

Bamboo bike | Spring bike | Itera plastic bike | Innervision IV-1 | Cardboard bike

The ***Bamboo bike*** is a bicycle consisting a frame made out of bamboo rods connected with carbon composite joints. Bamboo is a very light, strong, stiff and elastic material which is getting used more and more for different purposes. During a breaking tests of the bamboo rods, the designer found out that when filling the inside with a polyurethane foam (which added only few gram of weight), the rigidity increased. This technique is mainly executed for the seat and chain stay rods, which are the most critical parts of this frame. The overall weight of the frame is just 1860 grams. Because the unique properties of bamboo, as a natural composite, the frame is able to absorb road shocks and the ride is therefore more comfortable.

In the second picture a ***Spring bike*** is displayed; the idea is to wind up a constant power spring as a mechanical assist 'motor'. The spring is fitting inside the back wheel, and when the rider requires some power assistance, while riding up to a bridge for instance, the spring is released. When unwinding the spring produces mechanical torque onto the back axle. This idea of using mechanical power, is quite interesting but limited, electric assist have a for bigger action radius but are also more complex, heavier and expensive.

The ***Itera Plastic Bicycle*** was an attempt in the early 1980's in Sweden to reform and modernize the conventional bicycle design and production technology. Its basic idea was to replace metal by plastic fibre composite materials and take advantage of the modern production technology, based on automatised injection moulding technique. All essential parts, such as frame, wheels, fork and handlebar, were designed to be produced by automatic injection moulding, requiring very little subsequent finishing. Substantial grants and loans were obtained to start full-scale production in 1982. In spite of intense advertising and unusually high interest in the media, the new bicycle was never accepted in the marketplace. *"The bicycle boom after 1974's oil crisis, was already fading out, and few people were prepared to pay the relatively high price at which it was marketed. The bicycle was just as heavy as a standard bicycle, but it was slightly more flexible, which gave some people a sense of insecurity. The appearance deviated from the archetypal shape of a bicycle, and this is believed to have been the major reason for its rejection"* [Hult, 1992]. In 1983, 1000 Itera bicycles were purchased by the organizers of the national five-day orienteering contest. They were rented to participants who were also invited to buy them after the contest. All of the bicycles were sold on the spot. Even though it showed there was a market for the plastic bicycles, it was too late. Similar sales campaigns, such as lower prices, had been tried previously but they still failed.

The goal behind the ***Innervision IV-1*** project is to reduce costs and streamline the manufacturing process by using pre-moulded plastic components rather than aluminium tubes for the bicycle frame, producing a lightweight and affordable product for the cycling masses that could be made from, or turned into, plastic drink bottles. The designer was inspired to develop the prototype after first hand experience of the labour intensive processes involved in traditional bike building. *"Each individual tube has to be properly sized, notched, (if applicable) bent and then they're all individually welded together and if the frames are aluminium they require additional heat treatment. All of these processes occur before paint and the application of decals. These processes are very involved and require a lot of time and skill to do properly"*. Opting for the versatility of plastic, the designer came up with the Innervision IV concept which consists of an Inner frame for structural support and a two piece outer structure. The prototype version IV-1 is made of commercial grade polypropylene with reinforced polypropylene used for the rear chain stays. The components were thermoformed and then welded together using a combination of ultrasonic and hot air welding without the use of any adhesives. For the next prototype, the designer plans to use thinner, lighter, more rigid reinforced polypropylene for the outer casings which will be compression moulded. The new version will also utilize blow moulding for the Inner frame for further weight and cost reduction along with automated linear vibration welding to bring down assembly time.

The idea behind the ***cardboard bicycle*** is that it will be cheap enough to attract occasional users while also deterring thieves. The frame, made out of cardboard normally used in industrial packaging, could be produced for as little as £3. Once the wheels and chain had been added the total price might rise to only £15. The designer said: *"I started by looking at the reasons why people don't use bikes as a mode of transport, and one of the primary reasons I came up with was the initial investment in a bike. A typical round town bike can cost several hundred pounds, and that's a large investment for people who aren't sure whether they will use it. The idea of cardboard is to completely devalue the bike".* The cardboard for the frame is the material used in industrial packaging. It's very strong and it has a honeycomb core. It's mainly used in partition walling and packaging. The prototype does work but it is still quite limited and there are a few problems. The designer claims his bike is strong enough to support a rider, so long as he or she weighs under 12 stone. Perhaps more crucially, he insists that it is sufficiently robust not to go soft and collapse in the rain.


Piaggio MP3


Mitka


Roodrunner

The PIAGGIO MP3 is a totally innovative three-wheeler with two front wheels. The PIAGGIO MP3 provides safety, road grip and stability levels that no two-wheeler can match. Power, performance and ease of use make for a very entertaining ride. The two front wheels of the PIAGGIO MP3 re-define the very concept of ride stability to provide an unprecedented riding experience. The front assembly, with two independent tilting wheels, is far more stable than any scooter. The PIAGGIO MP3 grips the road even when tailing other vehicles, providing top performance in total safety. *[www.nl.piaggio.com].*

The Mitka is a hybrid vehicle, which is founded from a research perspective were multiple parties search together for a mobility solution of the future. Mitka is designed and engineered by TNO, Nike and Gazelle and uses both human and electric energy for driving. The idea is based on the fact that 80% of al personal transports is shorter than 20km. For distances shorter than 5km the bicycle is used a lot, but for longer distances people use the car. The Mitka could be most effective on the short distance range, where cars are most harm causing because of the pollution emissions, and therefore be a sustainable alternative for the car at short distance mobility. The Mitka intents to combine both benefits from the bicycle and the car, to be effective to a 20km range. *[www.kathalys.com/mitka].*

The TPG Roodrunner is a human powered mail transport concept. The concept reveals a new view on the carrier cycle, with a its large covered mail compartment, Ackerman steering system, electro-drive and chip lock. The purpose of the Roodrunner is to increase mobility of the mailman at strongly urbanised area's. The assist electric motor makes is possible to overcome bigger distances with less effort. Without the motor it may be extremely tiring for the mailman to drive the metal framed cycle and its mail capacity of 125 kilogram maximum. In this concept, ergonomics are very important. Therefore while steering only the wheels turn and the mass of the mail is stationary on the frame, resulting in a much easier steering system. *[www.iconenvandepost.nl]*

Appendix IV; *Scenarios (persona)*

1) Business couple

We both graduated a couple of years ago and we are now living in a pretty nice apartment in the centre of the city. We chose to live in the centre because we like to enjoy city live (theatre, restaurants, café, shopping, etc.) and it is quite near both of our offices; we can easily use the train or metro for commuting. We have to travel quite a lot for our carries; meeting in metropolis all over the world aren't rare for us. Usually, I stay over-night, attend meetings and take the early evening flight home. A downtown hotel puts me close to everything I need, so everything is within walking distance. Overall, the conditions are pretty perfect for the business traveller, except for the part where I drive the rental car back to the airport; I always catch rush hour traffic. Traffic is very chaotic in the city we live in, but luckily we do not need much shoppings. Most of the time we go out to grab a bite after a busy working day; neither of us likes to cook after work, and we are just to busy to do so. In the weekends we do most of our shoppings in a big supermarket. We go there with the car, but it takes a while to get there because of all the traffic lights. The supermarket is very crowded most of the time and it is difficult to conquer a parking spot. During the week one of us goes to the local shops (greengrocer, bakery and butcher) to get additional household things and fresh foods, if it is not to much to carry I prefer to walk. In fact we would like to use an additional shopping device, so we do not have to carry the shopping while walking back home. It has to be a kind of trendy machine, I feel ashamed when walking with a granny kind of shopping cart. We prefer a small, maybe electric device that you can take along in the shops. A bigger vehicle would be a substitute for the car we have, but it has to be sealed of to be able to store it safely outside. We do not have a garage or something like that, a bike or another small vehicle will be stored in the hallway or the small storage cabinet we have beside the toilet.

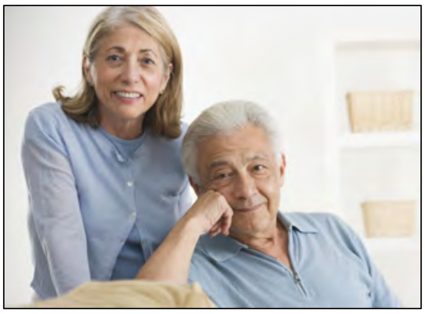
2) Family with kids

When we started our family, my husband and I chose to live in the suburbs. The cost of housing in areas closer to work were more than we could afford. A development in a new community on the outskirts of town offered us more house for the money. What we didn't fully consider, though, was the extra time and expense of commuting the longer distance every day. When gas prices spiked, our family budget was really squeezed. It turned out that the cost of driving exceeded the amount we paid for housing. We also chose this neighbourhood because we love the community, the schools are very good and shopping is fairly close-by. Still, everything is pretty spread-out, and it takes me at least 15 to 20 minutes to drive to most of my destinations. Let me tell you, the time can really add up. My husband and I both work full-time, so it's a challenge getting the kids to all their activities after we leave work. Traffic can be so unpredictable, which can be very stressful when you need to be places on-time. If transit service was more convenient, we could sell one of the two cars and still maintain our mobility and quality of life. Maybe if we sell one of the cars, I will get a carrier bike to bring the kids to school and sports. It will get me in shape and it may be even faster than the car. I like the products standing below because they stimulate ones health and also provide the ability to bring the kids along. Another factor I really like is the fun it gives while riding; I like to do sport but because of hectic family life I can not find the time to go to a sports centre myself. When the kids get a little older we could use things like kick bikes and scooters to go outside and enjoy nature in a fun way.

3) Students/Young couple

I've been successful in my studies at University so with graduation approaching, I have some good offers on the table from top employers in other cities. I like it here but am intrigued by the idea of city living with vibrant, dynamic places, diversity and culture and other young professionals like myself. At the moment I live in a student house with four other students. We have some household tasks during the week, so ones a week you have to do the shopping and prepare a meal. Because we are with five student we have to go to the supermarket a lot. Non of us can afford a car, and while walking or cycling you can only carry food for one day. I look forward to live together with my boyfriend; get some more space and privacy. But to afford even a little place, I would need a really nice salary. I could pay more for housing if I didn't have car expenses. I want to use a car to go to work if I can afford it, my bike to visit friends and maybe the bus is easier to get to the malls. The city I'll choose to live and work in has to have great places and transportation options that make great places possible, like walkable streets, bike lanes, buses and rail transit.

4) Elderly



My wife and I are long retired and live primarily on our social security income. We own our small town home on the outskirts of the city and our grown children are a 60 minute drive away. I care for my wife who suffers from a degenerative disease. Between the two of us, there are numerous doctor appointments that we go to through the week. My worsening vision makes driving more of a challenge and heavy traffic on the roads makes me afraid to drive. I love our home and our community, but getting out is becoming so difficult that we only leaving the house to do the bare minimum. If we had a better way to get to around, we could get out of the house more to get the things we need, maybe socialize with others more often. We have plenty of time and we both like to walk, an additional shopping cart might be handy because carrying the foods is quite hard when getting older. As mentioned before I do not like to ride the car anymore that much, instead I use the bicycle more often and I already bought bags for the bike. My wife used to walk with the dog, but her legs are getting worse. Now she uses a kind of pet stroller, it gives her support and the dog do not mind.

Appendix V; *Consumer storyboard*

Preparation


Making a shopping list

Get equipment


Use the stairs to leave apartment/house


Get downstairs with elevator


Get vehicle from shed

Transport


Cycling to a local supermarket


Parked cars in the garage of a shopping centre


Usage of the escalator to approach the supermarket

Parked bike with child trailer in front of entrance


Placed bikes in a bicycle rack nearby supermarket

Entering

Consumer in cart for disabled riding to entre

Walk with a shopping bag to entrance


Stored shopping strollers at service desk


Getting a shopping basket


Passing the entrance gate

Shopping


Blocked shopping paths


Female with shopping basket on top of pram


Female with maxi-cosi on top of shopping cart


Usage of a shopping basket


Searching for the foods you want

Leaving


Put the shoppings inside a vehicle


Leave supermarket with filled bags of shoppings


Manoeuvre through narrow doorways


Walk back home with a stroller


Get back in the car to drive away

In order to discover people's behaviour relevant to supermarket visiting, a storyboard has been made as you might have seen onto the previous page. Supermarkets in three different cities (Rotterdam, Delft and The Hague) were 'investigated'. Visitors were observed and pictures of their behaviour were made. (Because of supermarket policies I often was not allowed to take any pictures). In addition there have been numerous conversations between observer and visitors; this due to understand the problems, difficulties and annoyances of supermarket visitors in relation with home-supermarket transportation.

While observing I have seen that most of the supermarket visitors inside the city centres were walking or cycling, and were bringing their own bags and strollers along. Although they bring their own shopping equipment they change equipment at the supermarket's entrance. Most consumers are used to get a shopping cart or basket, resulting in interesting combinations of tools. I have seen trolleys inside shopping carts, bags inside baskets, big canvas bags hanging onto prams, a maxi-cosi on top of a shopping cart, a basket on top of a pram, etc. etc.

Most remarkable in this matter I found, the appearance of many 'granny' trolleys parked at the supermarket service desk. Walking visitors bring their personal shopping trolley and they store them in front of the supermarket service desk. It is not recommended by the supermarket to take those along inside the supermarket, because the consumer can not prove that earlier bought foods inside that trolley are already paid. This is the more or less 'official' reason from a supermarket perspective, from a consumer perspective those trolleys are not allowed because shoppings are no longer visible for supermarket staff. All foods have to remain visible at the supermarket in order to prevent theft.

A special group of visitors are young mothers with a baby pram. They use the pram as a substitute for a shopping cart, this because it is quite impossible to ride two – the pram and a shopping cart – at the same time. Therefore all shopping are getting stuffed in the luggage carrier of the pram (below between the wheels) or a shopping basket is used.

Another special group are the elderly; mainly using a shopping cart, because it provides stability (very often a walking stick is hanging or laying inside the cart) and one does not have to carrier anything (their amount of shoppings will easily fit inside a basket, but they prefer to use a big riding cart instead). In fact a lot of elderly visitors have their own shopping cart, namely a rollator, which gives them stability and the ability to store foods in its basket as well.

The approachability of inner city supermarkets is sometimes limited for certain groups of visitors. For example, car visitors in The Hague often have to park their car in a garage, where shopping carts are not allowed. The shopping carts have to remain at the supermarket area, so people have to bag their shoppings and walk to their car in the garage. The same problem arises with cyclists who have to park their bike onto ground level, and use the escalator to get underground to reach the supermarket.

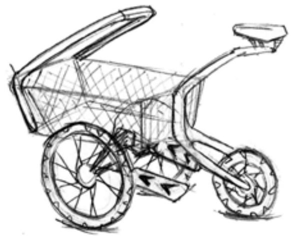
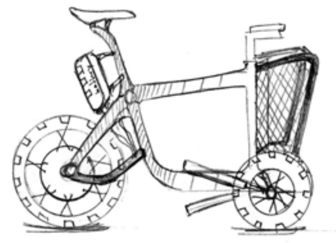
Although there are some bicycle racks, not all types of bicycles can be parked properly. Cyclist with a cargo/carrier bike or a kid trailer can not make use of the bicycle racks, they are forced to park elsewhere (sometimes resulting in obstructions for other visitors).

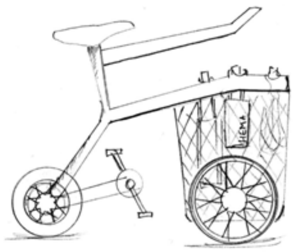
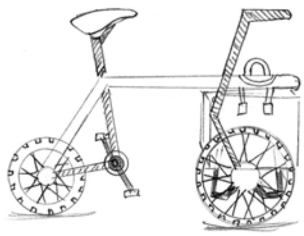
Inside the supermarket also some other obstructions were discovered. Quite often shopping paths are blocked because of the filling crew, which uses big metal carts. Also discounted products are blocking the paths; supermarkets want them to be noticed by visitors resulting in a negative effect in approachability.

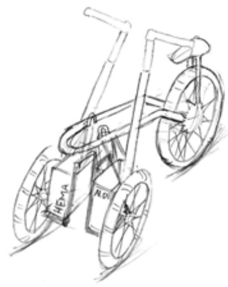
Also the entrances and exits are quite narrow; doorways are slit in half with metal poles and gateways are used to make sure only one costumer at the time can pass through the cashier. A big pole in the doorway is used to prevent visitors to take a supermarket shopping cart along outside. Disabled and mothers with prams had to entre and leave trough the emergency door (very unpleasant for visitors; have to wait for supermarket crew to open) which had to be opened and closed by personnel constantly.

Appendix VI; *Idea sketching*

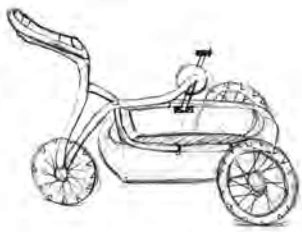


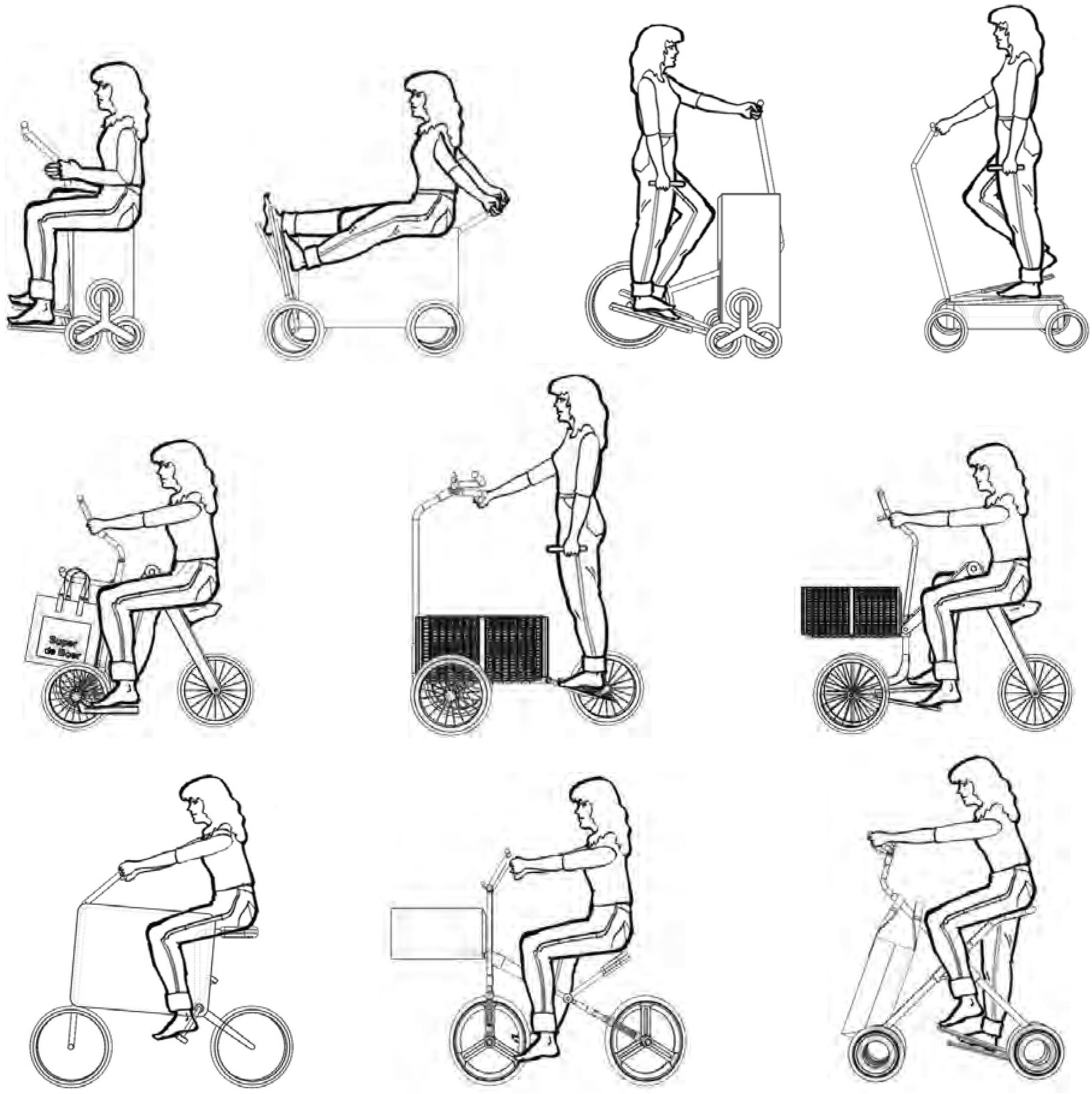




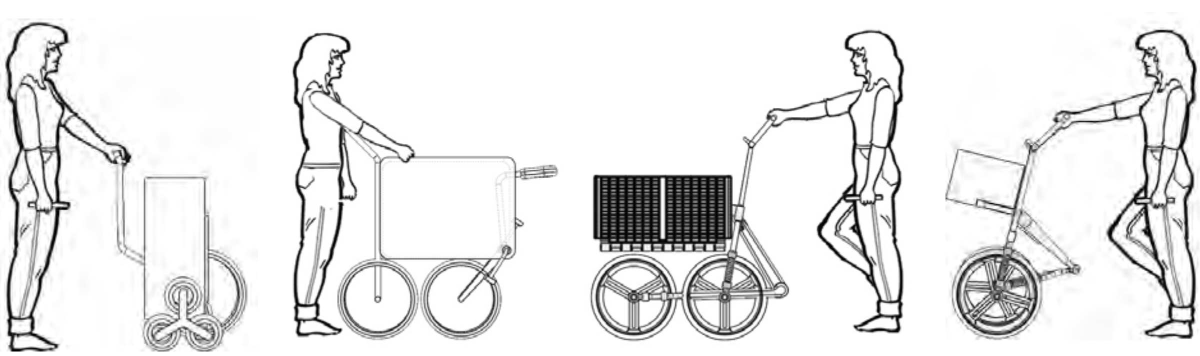



Appendix VII; *Structural variation*

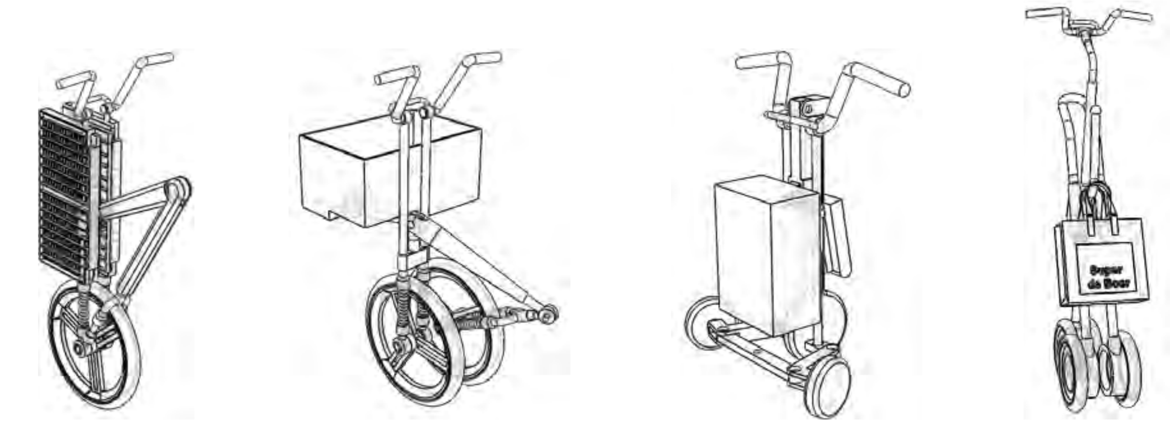
A: Riding



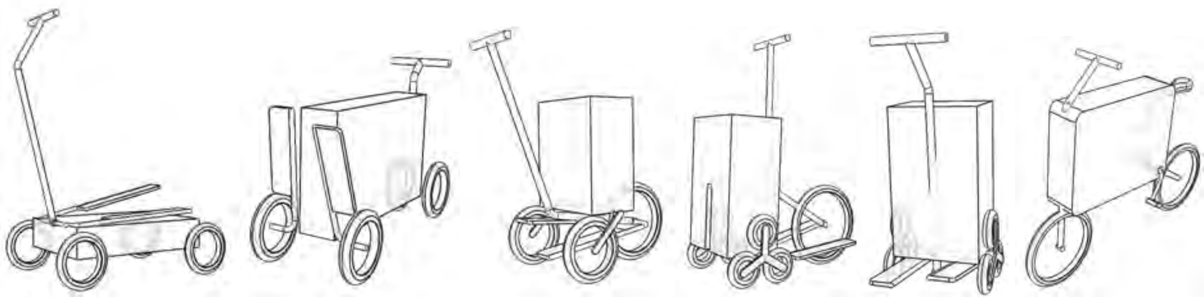
B: Strolling



C: Folding



D: Trolley + Bike =



E: Basket location and orientation

Appendix VIII; *Diverging*

Appendix IX; *Storyboard* | *Current situation*

Welcome in the Hague! Tom is living in this apartment, right here.

He already made a shopping list on paper, it's hanging onto the magnetic board.

Before going to the supermarket he also has to grab a big canvas shopping bag out of the closet.

He is leaving his apartment and locks the door behind him.

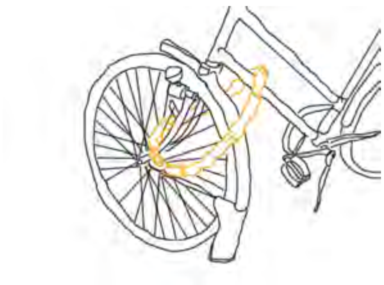
He uses the stairs to get to ground level.

Tom is leaving the building and goes downstairs.

He goes to get his bicycle from the shed.

He has to cycle only 1 km to the local supermarket.

When arrived at the supermarket Tom has to search a parking spot for his bicycle.



He put the bike against the wall and uses a chain lock to secure it.

Tom is now entering the supermarket trough the gateway. He grabs a basket and put his personal bag inside it.

In the supermarket he has to carry the basket all the time, and it is getting heavier and heavier.

Tom left the basket behind so he does not have to carry it all the time; it is easier when searching for some specific items.

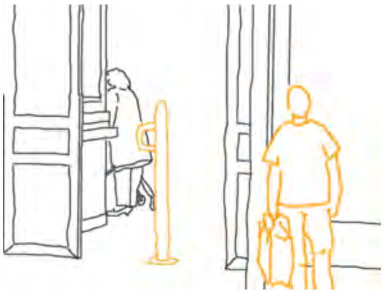
When the items are found Tom checks off onto his shopping list.

The basket is full, he thinks any more shoppings would not fit inside his bag. Time to go to the pay desk.

At the pay desk he unloads all individual sopping onto the conveyor belt and put the empty basket under the cash desk.

Now he has to wait for the cashier who is scanning his shoppings. Tom is paying with his cash card.

Tom is gathering his shoppings from the conveyor belt and put them inside the bag. The women next to him put everything back in the cart.



Tom can quite easily leave the supermarket, but the women with the cart has to reload her shoppings in bags. This because at this supermarket the carts are not allowed to be taken outside.

Tom is hanging the bag onto his bicycle steer. The bicycle is off balance now and Tom has to hold the bike steady to prevent it from falling over.

With the bag hanging onto the bike he cycles back home. It quite hard to steer smoothly, because the weight of the shoppings is pulling the steer to the left all the time.

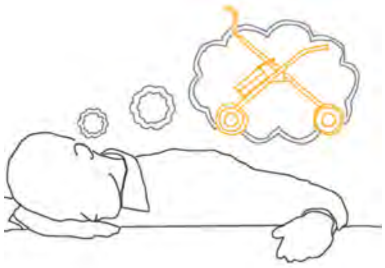
He is passing someone who went by foot to the supermarket. According to Tom it requires quite some effort to carry your shoppings all the way back home!

Back home, Tom put the bag on the ground and puts his bike back in the shed.

He has to carry the full bag upstairs and enters the building.

Now he uses the elevator to get back upstairs. Taking the stairs is very tiring.

Back in his apartment Tom puts the bag in the kitchen, and firstly put the cooled items into the fridge. He has to walk from and to the bag all the time.



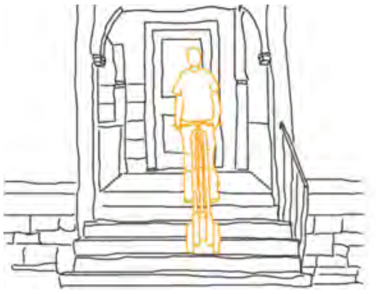
Tom it quite tired after shopping. Carrying the bag all the time requires a lot of effort and cycling with a bag onto your steer is very annoying. He dreams about the ideal solution!

Tom is still living in the same apartment in the city centre of the Hague.

He has bought a new shopping tool, which stands against the wall in his room. It uses a canvas bag and making shopping lists is embedded.

He is leaving his apartment with his shopping tool (which also contains a bag and the shopping list) and locks the door behind him.

He can still use the stairs to go to ground level. The device is able to roll down onto its small wheels.



Tom is leaving the building and goes downstairs. He pushes the device down first, the wheels roll down while he only hold the handlebars.

He unfolds the shopping tool in one single action, which makes it ready to ride!

He only has to step-cycle for 1 km to reach the supermarket. It is almost as fast as a normal bicycle, and way faster than walking.

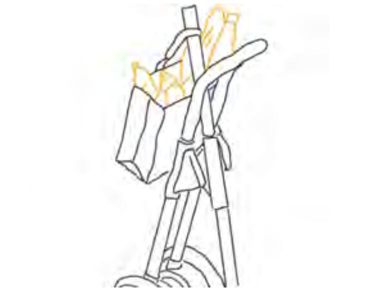
He does not have to search a parking spot, nor the vehicle has to be locked because it comes along inside.

Tom is now entering the supermarket with his shopping device. He folds the device so it will easily fits trough the gateway.

The slim vertical layout of the shopping tool makes it easy to manoeuvre trough the supermarket. It uses very little floor space.

Tom does not have to hold the device all the time. It will remain in balance and can stand on its own.

When the items are found Tom checks off onto the device itself.



The shopping bag is full; Tom now exactly knows how much stuff he can bring back home.

At the pay desk he unloads the shopping tool and puts all items onto the conveyor belt.

Now he has to wait for the cashier who is scanning his shoppings. Tom is paying with his cash card.

When gathering his shoppings, Tom put all the items right back into the shopping tool.

He can easily pas small doorways because of the slim vertical vehicle layout.

When outside, he unfolds the tool and rides back home.

He is passing someone who went by foot to the supermarket. Using the shopping tool is way faster and requires less effort.

At home Tom folds the tool, and drags it upstairs.

He uses the elevator to get back upstairs. The shopping tool stands on its own.

The device will easily fit inside the elevator. Tom leaves it there and is leaning against the rail.

Tom also uses the shopping tool inside his apartment. He puts it right next to the fridge to stuff the cooled items inside. Now he does not have to walk that much anymore.

Tom is very happy with his shopping tool. It does not require any preparation time. It goes faster than walking and does not require that much effort.

Appendix XI; *Prototype usability test*

Enter and leave

Entrance: sliding doors

Entrance: gateway

Cash desk: gateway

Participants were video filmed while entering and leaving the supermarket. At the entrance there is a small threshold because of the sliding doors; no one seems to have any problems with this situation. The 16inch wheels of the shopping cart are big enough to ride over the threshold and the door opening of the sliding door is big enough for the cart to enter. There are also some gateways inside the supermarket; one at the iterance and one at the cash desk. In both occasions the shopping cart did fit through the gateway, so the width of the cart does not seem to be a problem.

Turning around; some options

Back-and-forth; walk along

Back-and-forth; keep standing

Lift-and-turn

During the user test at the supermarket participants had to turn the cart around in order to follow their shopping route. Three different ways of turning around were discovered; these options are 1) back-and-fort; walk along, 2) back-and-forth; keep standing and 3) lift-and-turn. The tested prototype differs from a conventional shopping cart because the prototype has to be steered into its direction and a conventional shopping cart can be pulled into any direction. The steering mechanism of the prototype can be compared with the steering of a car. This means when driving forward steering movement is similar to the direction, but when driving backward one needs to counter steer because the steering mechanism works the other way around. People had some difficulties with this way of steering, because they were not prepared and did not expect this way of steering. In practice it was not possible to turn around in a shopping path with one single steering movement. This resulted into the fact that move back-and-forth movements were needed. When the shopping cart did turn around participants had to choose whether to walk along or keep standing. When people did walk along they remained behind the cart keeping their arms parallel at all times, but when people kept standing their arms had to cross in order to finalise the required steering actions necessary for turning. A total different way of turning around is the lift-and-turn; one participant did lift the rear wheel of the ground and made the cart pivot at the front wheel.

Put shopping in basket: approach

Approach side (35%)

Approach front (10%)

Approach back (55%)

Also the way people approach and put shoppings inside the shopping basked is observed. In 55% of the counted approaches participants positioned themselves at the back of the cart. While holding the steer, people reached over it in order to put shoppings inside the basket. Apparently the steer was not too high in order to do this. An alternative is approaching sideways, 35% of the counted approaches where executed in this way. In only 10% of the occasions the cart was approached at the front.

Put shopping in basket: posture

Bend; 1 arm loads (85%)

Bend; 2 arms load (10%)

Bend and twisted (5%)

Most items were put inside the basket one handed; 85% of the items were put inside the basket with this posture. Merely heavier items were placed inside the basket with two hands, this only occurred at 10% of the time shopping were gathered. A bend and twisted posture is quite seldom and only occurred at 5% of the occasions.

Bouncing

Against cooler shelf

Against refill cart

Against empty crate

As a result of the steering mechanism the two front wheels are cornering during steering actions. Because of this participants bounced onto several objects inside the supermarket. Although this was not a mayor problem in practice it validates the steering movement and how people expect the cart to ride. One participant bounced upon a cooler shelf, one almost bounced upon a refill cart and another participant bounced upon an empty crate which was lying on the ground.

Abandoning

During the test the shopping cart was abandoned sometimes. One participant did this twice; in order to get bread and ice-cream. She did this because it is easier to keep your shopping cart standing at a certain place sometimes and walk to the items you want to collect. This behaviour is independent from the type of shopping cart; she also does this with a conventional shopping cart. Another participant left the test cart behind because she was not able to reach the item because a refill cart was blocking the path.

Blocked path

Blocked by people

Blocked by refill carts

Blocked by objects

As mentioned before shopping paths are blocked sometimes by people, refill carts or other objects. Participants had to wait or walk around the blocking object. This was not any problem because the test cart was small enough to get trough anyway, and in one occasion the blocked item was pushed away with the test cart.

Opening fridge door

There are many fridges present inside the supermarket, in this supermarket these coolers had doors that opened to the outside. This means a shopping path becomes smaller; less standing area for participant and test cart. All participants parked the cart in front or behind the door so opening the door was not a problem.

Cash desk, unloading

Unload from back

Unload from side

Unload from front

When unloading the collected items at the cash desk, none of the participants complained about the crate height ore the steer blocking their unloading movements. Participants showed different positions while unloading; they were standing at the back of the test cart, but also at the side and front.

Cash desk, gather shoppings

Move in between

Remain at backside

Push steer aside

The items went over the conveyor belt and the participants put back the items inside the basket. All participants were standing at the back of the shopping cart, and some of them moved in between the cart and the cash desk. In order to do so they turned the steer aside to create more standing space, this has more to do with the steer width than the height.

Appendix XII; *Payment and rental system*

Assignment Smart Systems & Technologies

1.1 Assignment

This report describes the enrichment of the Stand-by Mobility Device for Local Purposes (SMDLP) with help of "Smart Systems & Technologies" ID4130 course content. The SMDLP is a design project of Rick van der Wee and is a graduation project at the Industrial Design Engineering (IDE) faculty of Delft University of Technology (TU Delft).

In this assignment at first trends (section 1.1.0) relevant to the SMDLP project will be analysed and described, those will be divided over the correlating disciplines of (1) bicycle industry, (2) supermarkets and (3) the user target groups. Secondly the SMDLP concept will be explained (section 1.1.1), and how the "Smart Systems & Technologies" course may enrich the concept. The gained knowledge and insights from the analysis will get used to enrich the SMDLP concept by implementing any of the working principals (section 1.1.2) as indicated at the ID4130 course topics: sensors, actuators, embedded software, batteries, displays and data transfer. On base of the topics, as described in section 1.1.2, a product model will be made (section 1.1.3) which visualises the product schematically. This report finalises with a Smart Systems & Technologies related redesign proposal (section 1.1.4), which encompass recommendations in order to enrich the SMDLP in terms of a more 'intelligent' product.

Index

1.1.0 Trends

First, it is important to see what kind of intelligence is already present in all the major stakeholders of this project. Developments and trends in bicycle industry, supermarkets and the user target group will get investigated and explained in the following sections.

1.1.0.1 Trends in bicycle industry

In the following I will describe some of the most outstanding developments and trends in today's bicycle industry. In the first I believe it is quite obvious to see similarities between developments that were first introduced in car industry and now settles in bicycle industry. In general I aim at topics like; integrating electronic components, on-demand navigation and rental systems.

Electronic components

One of the most important trends in current bicycle industry is making bicycles with electric assist motors. The technological development of compact battery packs on one hand and electronic speed chargers on the other made it possible to create vehicles with a relative big action radius. When riding the electric bicycle a sensor follows the movement of the rider's input at the pedals and provides assistance by the use of an electric motor, depending on the additional force needed to move forward. Real-time data is send to the micro-processor to activate the motor when needed, when the rider stops pedalling also the motor will stop.

Electric assist motor

Shifting gears is yet another bicycle application which has evolved from purely mechanical to electronic with the Shimano Dura-Ace Di2. The new Dura-Ace with Di2 technology brings shifting to a new level; it is easier now to always keep a tight grip on the handlebar and to keep your concentration on riding instead on shifting. Shifting is executed by simply pressing the button electronic and an electric motor does the rest. The electric shift system allows accurate and effortless shifting in difficult circumstances like cold hands or when you are completely exhausted. Furthermore, the shifting performance will never be affected by contaminated or stretched cables since the shifting signal is transferred electronically. In combination with the rear and front derailleurs the electronic shifters control the timing, movement and position of the derailleur for the perfect shift every time.

Electric shift system

Considering safety while riding a bicycle, lighting is very important and with interactive lighting safety may even increase. Two innovative products in this category are Winkku and the Firefly bicycle light. Winkku is a battery powered bicycle add-on which can be attached to the handlebar existing out of a combination of a mirror and a direction indicator light. The Firefly bicycle light can be considered intelligent; it uses a passive infrared sensor in order to detect traffic approaching from behind the rider. Upon detection LEDs flash onto the back of the rider with varying intensity depending on the proximity of the traffic. A set of LEDs also illuminate the ground beneath the rider; providing traffic with a proximity of depth which can be used to determine exactly where the rider is. There are many other bicycle lights available, but in the overall those lights help to indicate (1) presence, (2) direction and (3) speed/braking.

Interactive lighting

Bicycle GPS

Navigation

Bicycle GPS is a product in response to increase consumer demand for bike navigation, showing the best bicycle route that cars tend not to use. Beside that also information on bike parking, cycling paths, speed, distance covered, as well as burned calories for consumers who use the bicycle as a part of their exercise routine can be displayed.

Though still available in its beta phase and not found on in a mobile version any handheld gadgets just yet, the Google maps bicycle directions feature ought to eventually find itself on your mobile phone in the form of a free map. Users can type in different locations, say from their home to their office, and Google maps will give them the best route by bicycle. This is naturally not the same as the suggested car route, since Google maps takes into consideration all the available bike paths and bike trails, with preference given to bike trails.

Rental systems

The Paris Vélib bicycle scheme is a public bicycle rental programme in Paris, France. The system was launched on 15 July 2007; ten thousand bicycles were introduced to the city with 750 automated rental stations each with fifteen or more bikes/spaces. This number has since grown to 20,000 bicycles and 1,639 stations, roughly one station every 300 metres throughout the city centre, making Vélib' the largest system of its kind in the world. Paris residents and tourists can rent a bike for a couple of Euro a day, ride round the city (or commute to work), then drop off the bike at the end of the day. If a user arrives with a rented bicycle at a station without open spots, the terminal grants another fifteen minutes of free rental time. The rental terminals run on the Microsoft Windows operating system; displaying information about neighbouring Vélib' stations, including location, number of available bicycles and open stands. A fleet of 23 bicycle-transporting vehicles are used 24/7 to redistribute bicycles between empty and full stations. A credit card or Maestro debit card with PIN is required to sign up for the programme and to rent the bikes. The credit/debit card will be charged €150 if a rented bike is not returned. 1-day and 1-week subscribers are given a printed ticket with their subscription number that they will need for future rentals during their subscription period, while 1-year subscribers will be sent a RFID card. A trip that lasts longer than 30 minutes incurs a charge of €1 to €4 for each subsequent 30-minute period. The increasing price scale is intended to keep the bikes in circulation.

Paris Vélib

Berlin Call-a-bike

Montreal BIXI

Call a Bike is a bike hire system run by Deutsche Bahn (German Railways) in several German cities, which uses a system of authentication codes to automatically lock and unlock bikes. To find the bikes one has to search at the cross roads in the central areas of the towns or use location-based services on modern cell phones to find them. A simple call to the customer service centre to locate the call-bikes is not on offer anymore. Customer calls the telephone number given on the bike which includes the bike's ID and gets by voice the 4 digit opening code, which he then types onto the bike's touch screen to unlock it. Lock the bike to a fixed object, and select "return bike" from the bike's touch screen. A code will be generated which then has to be telephoned to the control centre, as proof that the bike was locked. As well one has to give the exact street names of the cross roads, which has to be within the permitted town area. The cost is 8 Euro cents per minute; holders of a BahnCard get a reduced rate of 6 cent per minute; there are also reduced rates for 24 hours or a week of use. In Stuttgart the first half hour of use is free. The system uses an electronic wheel lock and a cable lock, all controlled by embedded microcontroller with touch screen LCD display. A set of 1024 pre-generated lock/unlock codes are unique to each bike and stored in memory.

Public bike systems are an environmentally friendly and practical urban transport solution, and in theory they benefit everyone in town, but sadly, most programs quickly fold when the bikes are routinely stolen or smashed by vandals. Montreal's Public Bike System (BIXI) plans to use clever design, RFID and a membership system to see if they can keep a public fleet of bikes on the road. By attaching a small rental fee to the bike system, payable only by credit card or membership card, the Public Bike System aims to make each rider responsible for the time they spend on a bike and ensuring its safe return. All bikes are RFID-tagged, and can be picked up from one station and delivered to another. Pay stations are touch screen-operated and only accept credit cards. A button is used to notify BIXI mechanics of defective bicycles. When the bike is returned, the appropriate rental fee is deducted, encouraging people to keep their usage times short and thus keep the bikes in circulation.

1.1.0.2 Trends in supermarkets

Supermarkets try to stimulate sales (by increasing loyalty and efficiency); in order to do this loyalty programs, new payment systems and monitoring customer buying behaviour is applied. One of the most active, and innovating supermarkets in the Netherlands is Albert Heijn Supermarkets. I will use Albert Heijn as an example in order to describe current developments at supermarkets.

Loyalty programs
"Loyalty programs are structured marketing efforts that reward, and therefore encourage, loyal buying behaviour — behaviour which is potentially of benefit to the firm. In marketing generally and in retailing more specifically, a loyalty card, rewards card, points card, advantage card, or club card is a plastic or paper card, visually similar to a credit card or debit card, that identifies the card holder as a member in a loyalty program" (Wikipedia, 2010). Albert Heijn has a loyalty program know as the "Bonuskaart", which is a plastic card with a barcode on it. The card will be scanned by the cashier to activate discounts on items that are inside the discount program of the current purchase. Customers had to fill in an application form in order to take part in the loyalty program, which means the supermarket is able to link certain purchases onto an indentified customer and this data will be used as part of the supermarket's marketing research.

Shopping lists
Supermarkets do provide the ability to create shopping list via the internet; people are able to see discounts and recipes onto the supermarket's website for instance, the desired shopping items can be selected and put upon a virtual shopping list. De Albert Heijn "Mijn boodschappenlijst" is such a web-application to create shopping lists, and all previously bought items can be viewed by entering the loyalty card number. One disadvantage of the shopping list via internet is that the list has to be printed, and therefore is unchangeable.

A more interactive alternative is the new "Appie" application of Albert Heijn. The Appie is an iPhone application in which one can find over 8.000 recipes, previously bought items and the discounted items. Items can be searched and selected in order to create a shopping list. Albert Heijn wants to make buying groceries as easy and pleasant as possible for its customers and expects smartphones and the internet play an increasingly important role in communicating with the customer. Navigating is another function that is integrated in the Appie tool; with the store-locator it is possible to find the nearest Albert Heijn supermarket and its business hours and via Google Maps is possible to create a route to the location. With the new 1.5. version of Appie it is also possible to navigate inside the store; the items on the shopping list are organised according to the regular walking route of that particular store. In the future the Appie application will also be made available for Android based smartphones like HTC, LG, Sony-Ericsson, Dell, Motorola, Acer, Samsung and more.

Payment methods
Nowadays the standard payment method in supermarkets is paying with cash or by PIN, but when looking to the near future this might change. Currently every product has its own barcode (optical machine-readable data represented by parallel bars varying in width and spacing) that can be read by optical scanners. The also called UPC (Universal Product Code) number is send to the store's central POS (point of sale) computer to look up the price. This approach allows the store to change the price whenever it wants; if the prices were encoded in the bar code itself, prices could never change. Customers can pay by pulling a debit card with a magnetic strip on it trough the card reader and enter the corresponding PIN (Personal Identification Number) 4-digit numeric code. Supermarkets are investigating how to make payment systems even less time consuming (scanning all individual UPC barcodes takes the most time); the increase in payment efficiency will have a positive effect onto customer satisfaction according to supermarkets. In the following I will describe some of the latest developments in payment methods at Albert Heijn supermarkets.

In order to avoid long checkout queues Albert Heijn introduced a "Self-scan" system at its XL-stores. Customers use a handheld scanner to scan the product's barcode before placing it inside the shopping cart. The scanner is linked to the customer's loyalty card and when all items are gathered people can pay for the shoppings at a self-service payment pole. Checks on theft are done randomly by supermarket employees.

Albert Heijn supermarkets also started a test in corporation with Equens (payment processor) on a new fingerprint identification based payment method called "Tip2Pay". The involved companies state that paying with your fingerprint is fast, easy and safe and the main goal of this test is to investigate whether customers become enthusiastic about this payment method. Tip2Pay is an alternative for cash or PIN transactions and has the advantage of combining all former accounts (debit card with bank account involved, loyalty card with discount points and personal identification) into one system; the fingerprint. The only thin a customer has to do is scanning the index finger at the cash desk.

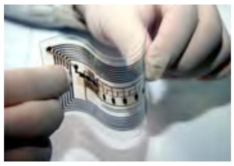
Yet another payment method that is tested by Albert Heijn is paying with your cell phone. This mobile phone payment allows customers to scan and pay the shoppings themselves. A special NFC (Near Field Communication) phone is needed; by holding the phone next to a product's price tag the items is scanned, and all shoppings will be paid by holding the phone next to a cash point. NFC is a method based onto RFID (Radio Frequency Identification) technology which makes it able to transfer data between appliances over very short distances. Communications between the appliances probably will be arranged by the use of "Payter" which in fact uses software in order to make a digital wallet from your mobile phone. The digital wallet in fact is a prepaid system in which users have to upgrade their account before making transactions. Currently the money has to be transferred from the personal bank account into an ABN Amro suspense account, but in the future it may be possible to link Payter directly (so no prepaid) to your personal bank account.

A related development relevant to more efficient payment methods in supermarkets is the introduction of the so called "RFID-tags" as a replacement of the UPC barcode. As mentioned before scanning all products once at the time is quite time consuming and this can be done more efficient when using radio waves instead of optics when transferring data. The main advantage of using radio waves is that products can remain inside a basket or shopping cart while sending a signal; this may result in checkout line-free shopping in the future. *"The inexpensive, printable transmitter can be invisibly embedded in packaging offering the possibility of customers walking a cartload of groceries or other goods past a scanner that would read all the items at once, total them up and charge the customer's account while adjusting the store's inventory" (Quick, 2010)*.


Self-scan


Appie


Tip2Pay


RFID-tags


Payter

Transportation
Albert Heijn supermarket has a delivery service "albert" which is directly linked onto the webshops of Albert Heijn (supermarket), Etos (drugstore/herbalist) and Gall&Gall (liquor store). With this delivery service customers can place their order via internet at the www.albert.nl website and the shoppings will be brought at the address by delivery vans. The order has to be paid by mobile PIN at time of delivering at the address. Although this is the standard payment method for albert, there also is an option to permit direct debit or in case of corporate clients pay by invoice.

In September 2009 Albert Heijn started a try-out with bicycle trailer cards, named "iShop". In cooperation with Dutch bicycle company Gazelle Albert Heijn started a pilot test of 50 bicycle trailers which could be attached at the back of a normal bicycle. The iShop can be taken along inside the supermarket while gathering shoppings, afterwards the iShop is reattached to the bicycle and customers can cycle back home. Albert Heijn investigates whether this new manner of supermarket visiting suits customer needs. This initiative is supported by local government because promoting transportation by bicycle is expected to improve living conditions and accessibility of inner cities. Municipalities provide facilities like free guarded bicycle parking, bicycle lanes separated along main roads and with additional services like charging points for electric bicycles and bicycle pumps they try to seduce the local residents to choose the bicycle for short distance transportation.

1.1.0.3 Trends at user target group

The target group will be set by means of the consumer needs relevant to mobility. The focus is on a mobility device as an attribute for shopping (carrying) purposes. In more or inferior degree all people have to deal with this, but the ones that are most representing are the people living in highly urbanised areas, and do not have a car. Dependent on the household situation and their activities the "Stand-by Mobility Device for Local Purposes" could function as a substitute for a car. These people are between 20-40 years old and do like to live in strongly urbanised area's because of the many activities present. It is most common for them to rent a city apartment, or to buy a house in or near the city centre. These people are commuters, travelling every day from and to their jobs. The couples in this target group are most of the time double-income household; working full-time both or one of them may be working part-time.

In this section the focus is on technological based developments, relevant to the subject of the SMDLP concept in which the user target group might benefit from in the future. In order to spot trends that matter for the target group and also interface the SMDLP project and the Smart Systems & Technologies course content, various trend spotting web-pages were consulted.

Social media

In the 2010 trend report of Mr. Bakas *(Bakas, 2010)* one can read about the possible influence of social media such as YouTube, Facebook and Twitter on business marketing and advertisements. *"Social media are media designed to be disseminated through social interaction, using highly accessible and scalable publishing techniques. Social media use web-based technologies to transform and broadcast media monologues into social media dialogues. They support the democratization of knowledge and information and transform people from content consumers to content producers" (Wikipedia, 2010)*. Bakas expects businesses will expand their marketing activities trough social media, and beside that social media will get more and more integrated in our lifestyle by implementing it in mobile phones (smartphones) for instance. Many companies/brands will utilize social media in the future; attempting to reach potential consumers and build or maintain reputation.

Augmented reality

In a Dutch article about ten techniques that would change the world *(Zweers and Van Leeuwen, 2010)* the authors mention the rise of augmented reality. Augmented reality is the ability to merge a view of the physical world with enhanced data or imagery that is computer generated – thereby providing a richer view of the real world. Using the GPS, the camera and even the compass, your smartphone can sense what you are pointing at and show relevant data for that place, such as reviews for a restaurant or virtual signposts to direct you to a place.

Smartphones

Currently there is an extensive growth in the amount of smartphones reaching the marketplace, and the continuing rise of smartphone usage encounters for an increase in data traffic. This is due the fact that more and more functionalities (camera, compass, GPS, etc.) were integrated in mobile phones the last couple of years. This in combination with software development platform that allow application developers to create all kind of new applications that add functionalities to the smartphone, made the device fit in people's modern lives perfectly.

Smart surroundings

The world around us will become more and more intelligent *(Zweers and Van Leeuwen, 2010)*, and according to the authors this is because in the future more sensors are used to measure our desires and needs and make systems act on it mostly unnoticed. Sensors that are embedded in the surroundings we live in do make the surrounding smart; monitoring processes, error control, increase of efficiency and dropping the costs are some of the main tasks sensors are used for.

1.1.1 Product properties

1.1.1.1 The SMDLP concept

The SMDLP is a multi-functional mobility device, designed for supermarket visiting. The concept can be best imagined as a fusion of a carrier cycle, shopping cart and baby stroller. Namely the SMDLP has three comparable configurations: (1) cycling - riding mode, (2) shopping - walking mode and (3) storage - stand-by mode. This enables people to use the same device for both transportation and supermarket visiting.

SMDLP: cycling - riding mode

This idea of combining three yet existing functionalities into one device came forth from the idea that current transportation means are lacking in efficiency in case of supermarket visiting. (Travelling by car may cause traffic-jams, environmental pollution and fatal accidents; using the public transport may result in delays and by riding a bike one is exposed to the weather conditions and unable to transport bigger loads safely; walking requires a lot of effort and time). Being mobile at most profitable way requires proper decision making, because in every situation people can choose between several available transportation means.

People have to decide whether they go by car, public transport, bicycle or walking to the supermarket. Especially citizens, living in highly urbanised areas are limited in transportation abilities; because of limited parking space for cars and bicycles, busy travel routes and crowded supermarkets.

The SMDLP intents to be the alternative: the device is an attribute 'dedicated' to supermarket visiting. People living in highly urbanised areas could use the SMDLP to transport (over short distances of 0-1km) themselves to the supermarket, gather shoppings (average is 7,5 kg and max 15kg) inside the supermarket with it, cycle back home and take the SMDLP along inside when storing the shoppings in the fridge or closets. The SMDLP can be folded into a compact package so people are able to store the device itself; 'stand-by' in the hallway, balcony or any room.

1.1.1.2 Enrich the concept

The initial idea was to design the SMDLP at a design studio in corporation with a bicycle company. The device was planned to be made by the bicycle manufacturer and with use of their current distribution lines directly sold to the end users (with low cost of ownership in mind).

This means the design studio is responsible for the overall design in corporation with the R&D department of the bicycle company. The bicycle company will produce the SMDLP at their bicycle factories and a distributor will transfer them to the bicycle shops. In this scenario the user buys and therefore owns the product (no high sales quantities guarantied), which means the user is free to visit any supermarket with it when supermarket policies allow entrance.

The supermarket is a very important stakeholder, but is left out in this marketing plan. There is a high risk supermarkets will eject the SMDLPs from their supermarkets because they can not benefit from it in any way. With this insight it is recommended to investigate how to involve supermarkets in the SMDLP project and spread the risks.

An alternative is to sale the SMDLPs to the supermarket (guarantees high sale quantities) and implement some sort of customer bonding with help of an 'intelligent' system. In this scenario supermarkets have to invest in purchasing the SMDLPs and in combination with a rental system they can profit from customer loyalty. With this system supermarkets can transform into a new formula where less conventional shopping cart, car parking spaces and bicycle racks are needed. In this manner users can freely make use of the supermarket's SMDLP rental system (no cost of ownership) but are bond onto that one specific supermarket chain when using its transportation mean.

The investments of the supermarket in the SMDLP project can partly be paid from the savings made on conventional shopping carts and other car based supermarket visits, like parking spaces. On the other hand the SMDLP can be used as a promotion tool for: (1) improving the supermarket's image with the sustainable character of the SMDLP and (2) use the SMDLPs as free advertising material riding around in the city. The rest of the investments should be recouped by the strengthened customer loyalty and the corresponding turnover improvements. To do so it is important for the supermarket to have maximal efficiency in usage of the SMDLP with minimal investments. This means an 'intelligent' rental system (this is where Smart Systems & Technologies is applicable) is needed to stimulate usage of the SMDLP but also make users hand in the device quite fast so someone else can use it.

Yet another possible enrichment of the SMDLP project might be a payment system that makes supermarket checkouts run smoother in terms of user comfort and ease. The SMDLP is used inside the supermarket as a substitute for a normal shopping cart, which means all shoppings are already in its final transportation device. It makes no sense to unload at the cash desk in order to sum up all individual costs and pay the total, and after all re-loading the shoppings in the SMDLP. It would be ideal to leave all shoppings inside the SMDLP, and just pay automatically while leaving the supermarket.

1.1.1.3 Proposed properties

The SMDLP can be enriched by the implementation of both (1) a rental system and (2) a payment system integrated into one (3) overlapping system. These systems may exist out of new technologies as described in section 1.1.0 about trends. It is important to keep in mind both systems do function on behalf of partly similar technologies. For example RFID in combination with NFC can be used in both situations, whereas in both occasions a smartphone links a product (groceries or bicycle) to customer identity in combination with product use or purchase.

In short; techniques used in the rental and payment system are enumerated underneath in order to form the overall system:

(1) Smartphone + NFC + GPS + Google maps + GSM/UMTS + Call-lock = Rental system
(2) Smartphone + NFC + RFID-tags + POS + Payter = Payment system +

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(3) Smartphone + NFC + RFID-tags + POS + GPS + Google maps + GSM/UMTS + Payter + Call-lock = Overall system

In the following section "1.1.2 Product (analysis) layout" I will describe the techniques used in the overall system in detail. It is decided to only describe the system in its total to prevent telling the same story twice partly. Subjects of the Smart systems & Technologies course content (such as sensors, actuators, embedded software, batteries, displays and data transfer) will be used as guidance for describing the product layout.

1.1.2 Product (analysis) layout

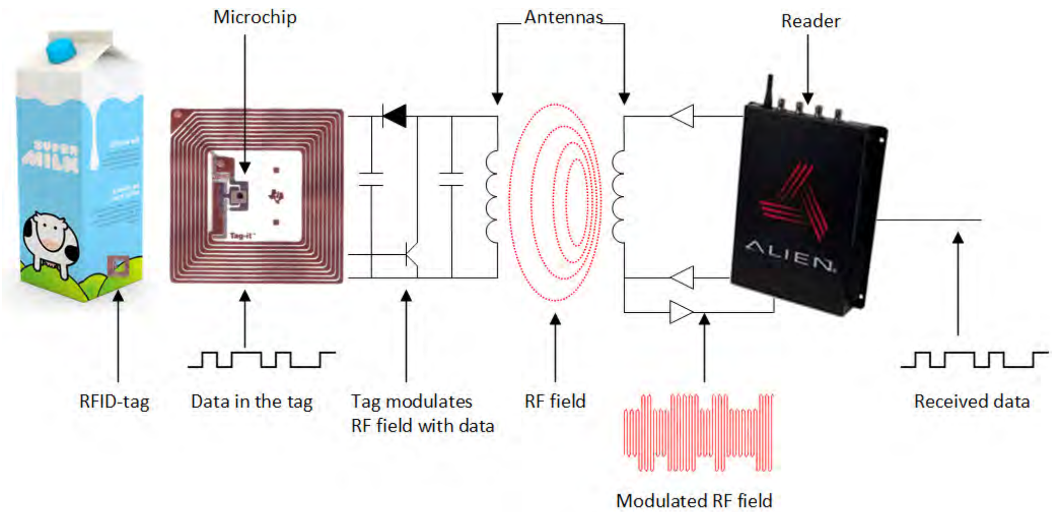
1.1.2.1 Sensors

• Antenna **(sensor)** – *converts electromagnetic waves into electric current.*

The term sensor can be defined as *"any device that receives a signal or stimulus and responds to it in a distinctive manner"* *(www.dictionary.com).* This principal is used by radio frequency identification (RFID) tags, were radio waves (electromagnetic energy) are transformed into digital data (electric current) and vice versa.

RFID tags are intelligent bar codes that can communicate to a networked system via an electronic interrogator (reader) in order to track products and send additional data from the tag's embedded memory to a middleware application. In general, modern RFID-tags can be divided into three categories; active, semi-active and passive RFID-tags. *"These tags can sore up to 2 kilobytes of data and are composed of a microchip, antenna and, in case of active and semi-active tags a battery"* *(Bonsor and Keener , 2007)*. The internal battery is used to power their circuits and active tags also use its battery to broadcast radio waves, were semi-active tags use their battery to boost the tag's range. Because these tags contain more hardware than passive tags, they are more expensive which makes them less appealing for large scale implementation at supermarkets.

Passive RFID-tags are quite inexpensive (according to *Wikipedia, 2010* they can be as cheap as 4-10 cents) and rely entirely on the reader as their power source; the reader sends out an electromagnetic (radio) wave with its antenna, this activates and powers the tag. This is possible because the tag also contains an integrated antenna **(sensor)** that converts the electromagnetic wave by means of induction into electrical current in the tag's coil.



When the passive tag draws power in this way the resultant interaction of the RF field causes the voltage at the reader's antenna to drop in value. This effect is utilized by the tag to communicate its information to the reader. The tag is able to control the amount of power drawn from the field and by doing so it can modulate the voltage sensed at the interrogator according to the bit pattern it wishes to transmit. So using power harvested from the reader's electromagnetic field, the tag sends radio waves back to the reader. The reader picks up the tag's radio waves and interprets the frequencies as meaningful data.

In the SMDLP project RFID-tags will be used both for indentifying groceries and the vehicle as well for payment authentication. The groceries at the supermarket will be equipped with an Alien Technology® ALN-9629 "Square" inlay RFID-tag suitable for such asset tracking operations. This ALN-9629 Ultra High Frequency (UHF) tag consists of 860-960MHz transponders that are compliant with EPC global Class 1 Gen 2 standard ISO18000-6C. This tag has a range of 3-5m approximately due to its usage of ultra high frequency radio waves, as displayed in Zebra's *"Passive RFID Standards"* Table *(Zebra, 2009)*. This range is reader dependent and therefore can also be set to a preferred lower range (1-2 meters) in order to eliminate multiple customers scanned at once while checking out.

A Near Field Communication (NFC) chip is integrated inside a smartphone for enabling payments. *"The technology is similar to the RFID transmitters, except that NFC chips allow for two-way communication instead of only one way, which is supposed to make for a more secure payment method* (Layton, 2007)*.* The technology behind NFC, like RFID, uses inductive coupling to transfer data; only NFC uses a lower frequency of 13.56 MHz with a bandwidth of 14 KHz resulting in a shorter range of 10cm approximately. A NFC chip capable of communicating in such manner, *"regardless of protocols and operating systems"* (Clark, 2009) is the Movera USAM chip.

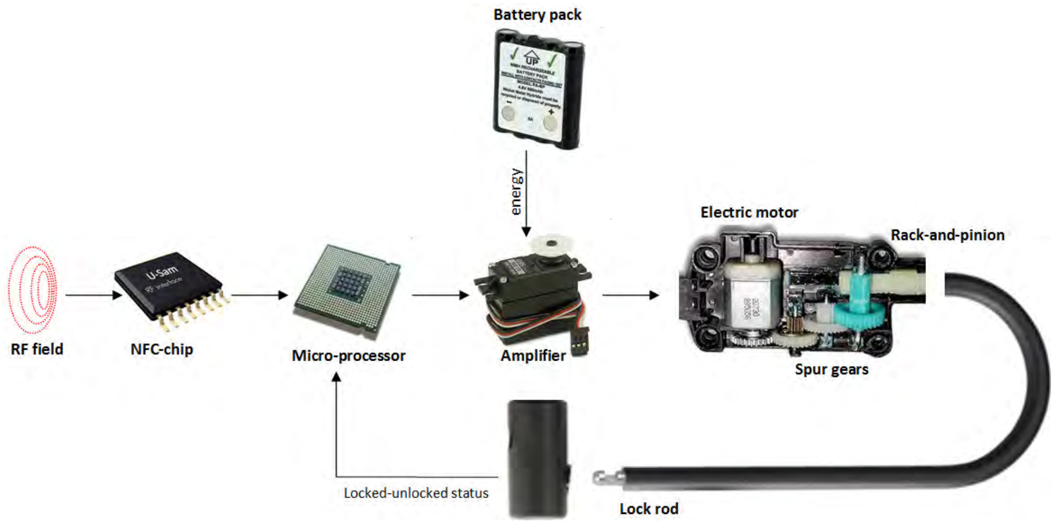
1.1.2.2 Actuators

• Antenna **(actuator)** – *converts electric current into electromagnetic waves.*

• Electric motor **(actuator)** – *Converts electric current into rotary motion.*

In this SMDLP project system the electronic RFID reader is continuously sending out electromagnetic waves; searching for and thereby activating the RFID-tags. The earlier announced antenna **(actuator)** in fact is a transducer that can operate in either way sending and receiving; that is why it is both a sensor and an actuator. The radio wave signal from the RFID-tag is received at the reader's antenna, transformed into an electric signal and interpreted as digital data with help of a middleware application embedded in the reader.

In case of making a payment the digital signal will be send to the supermarket's point of sale (POS) database in order to retrieve actual prices. These price data will be send to the cash register to calculate the total amount. The cash register may then transmit the amount due to a NFC reader to receive payment.



In case of using NFC technology in order to rent a SMDLP vehicle, the received signal will be used for authentication and an additional activation code can enable an electric lock to open or close. The SMDLP will be equipped with an electronic lock that mainly consist of a receiving (NFC-chip), a controlling (microprocessor) and an executing (electric motor) device. When the microprocessor receives the correct digital code, it provides power via an electronic amplifier to the electric motor **(actuator)** that unlocks or locks the SMDLP vehicle for a timed interval. The small electric motor turns a series of spur gears that serve as a gear reduction. The last gear drives a rack-and-pinion gearset that converts the rotational motion of the motor into the linear motion needed to move the lock.

An actuator typically is a mechanical device that takes energy and converts that into motion, and a typical example of an actuator is the electric motor as mentioned in the TUDelft-IO 2010 Electronics Reader. The electric motor used in above displayed system is the NF243G-103 Johnson Eclectic PMDC Motor; where PM stands for Permanent Magnet and DC for Direct Current. This motor is quite small (Ø 24.2 x 70.7, flat 18.3, shaft Ø 2mm) and runs on a nominal 12VDC.

PMDC motors are the most common, least expensive and lightest type of motors. This type of electric motor contains two small curved permanent magnets (north and south) in order to interact with the motor's armature in terms of attracting and repelling forces. The permanent magnets are embedded into a steel can that forms the body of the motor that remains stationary (and therefore is called the stator). The armature (also called the rotor, which is the rotating element of an electric motor) has three electromagnetic poles made by winding copper wire around a piece of metal. By applying electric current to the armature the copper windings become magnetic, and another north and south start to exist dependant on the direction of the electrons flowing in the wire (electromagnetism). This is regulated by the motor's commutator and the two brushes; *"they work together to let current flow to the electromagnet, and also to flip the direction that the electrons are flowing at just the right moment. The contacts of the commutator are attached to the axle of the electromagnet, so they spin with the magnet"* *(Brain, 2003)*, only making contact in the desired phased positions. This makes the field of the electromagnet flip in order to create a continuous attracting (north-south combination) and repelling (north-north or south-south combination) which makes the armature and axle rotate smoothly.

1.1.2.3 Embedded software

• eXtensible Markup Language – *language used in tags.*

• Middleware – *connects software components or applications.*

• Firmware – *execute low-level operations in electronic devices internally.*

• Operating System – *managing hardware and software.*

• Application Execution Environment – *application programming interfaces.*

The information stored in the small passive RFID-tags would be written in a Product Markup Language (PML), which is based on the ***eXtensible Markup Language (XML)***. *"PML would allow all computers to communicate with any computer system similar to the way that Web servers read Hyper Text Markup Language (HTML), the common language used to create Web pages"* *(Bonsor and Keener, 2007)*.

As mentioned before the data from the tag's embedded memory is received by a reader and with use of a ***Middleware*** application interpret as meaningful data. *"Middleware is especially integral to modern information technology based on XML, SOAP, Web services, and service-oriented architecture"* *(Wikipedia, 2010)*. In fact Middleware sits 'in the middle' between application software that may be working on different operating systems. This makes it possible, for instance to use the tag's information and make it 'speak' with the POS database in the supermarket while both use different languages, the middleware functions here as some sort of 'dragoman'.

In the SMDLP system the electric powered lock as described earlier is also equipped with some sort of software in order to execute simple tasks on a component level. The embedded software in the lock is called ***Firmware***, and denotes the fixed, usually rather small, programs and data structures that internally can control this electronic devices. Firmware is typically involved with very basic low-level operations (control the electric motor in this occasion) without which a device would be completely non-functional.

But the most important element, when speaking about software, is the smartphone which can be considered the 'spider-in-the-web' of this very SMDLP system. *"Smartphones allow individual users to install, configure and run applications of their choosing. A smartphone offers the ability to conform the device to your particular way of doing things"* *(Coustan and Strickland, 2007)*. This means a smartphone could be a suitable device for distributing both the SMDLP payment and rental applications.

The smartphone is capable of doing so because of its extensive software stack and according to Coustan and Strickland this stack consists of the following layers:

- ***Kernel*** *- management systems for processes and drivers for hardware.*

- ***Middleware*** *- software libraries that enable smartphone applications (such as security, web browsing, messaging, etc.)*
- ***Application Execution Environment (AEE)*** *- application programming interfaces, which allow developers to create their own programs.*
- ***User Interface Framework*** *- the graphics and layouts seen on the screen.*
- ***Application Suite*** *- the basic applications users access regularly such as menu screens, calendars and message inboxes.*

"The most important software in any smartphone is its ***operating system (OS)****. An operating system manages the hardware and software resources of smartphones. Some OS platforms cover the entire range of the software stack. Others may only include the lower levels (typically the kernel and middleware layers) and rely on additional software platforms to provide a user interface framework, or AEE" (Coustan and Strickland)*. Little devices such as smartphones nowadays contain quite advances small computers to run an operating system, in fact it is the first thing loaded when turning the device on. In the SMDLP system an iPhone 3Gs could be used for instance, and the operating system it runs on is called Mac OS X. It manages the keypad, the screen, the address book, the phone dialer, the battery and the network connection, and without this piece of software the device would be useless. So managing the hardware and software is very important, as various programs and input methods compete for the attention of the Central Processing Unit (CPU) and demand memory, storage and input/output (I/O) bandwidth of their own purposes. The CPU, or also called Applications Processor used in the iPhone 3Gs is the ARM A8 Samsung S5PC100 which has a clock speed of 600MHz. In this processor the ARM architecture, suitable for low power applications, is used. ARM based processors are the most energy efficient and this made the dominant in the mobile and embedded electronic market.

Because of the extensive software stack that already is embedded in the smartphone only additional applications for rental and payment operations of the SMDLP system have to be added at the AEE layer. For enabling payment by mobile (smart)phone, Payter which is such an application can be used (see section 1.1.0.2 about payment methods). In case of enabling rentals of SMDLP vehicles, an application that manages user authentication, vehicle reservations and usage in combination with location tracking has to be made.

1.1.2.4 Batteries

• NiMH battery – *powering the electric motor of the lock*

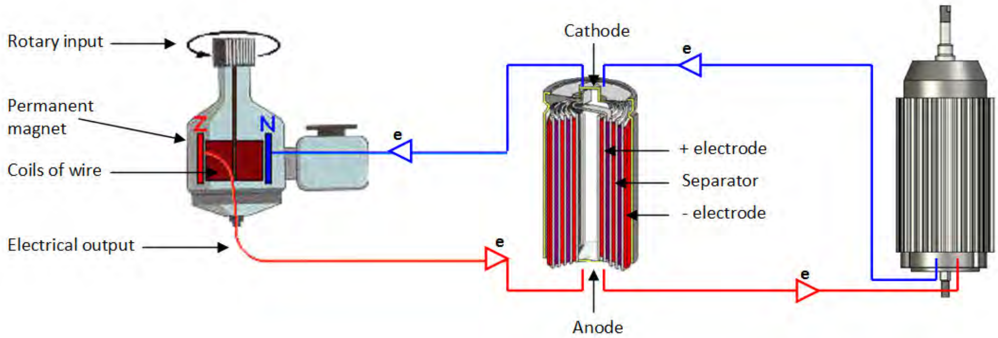
• Li-ion battery – *powering the smartphone*

"An electrical battery is a combination of one or more electrochemical cells, used to convert stored chemical energy into electrical energy. There are two types of batteries: primary batteries (disposable batteries), which are designed to be used once and discarded when they are exhausted, and secondary batteries (rechargeable batteries), which are designed to be recharged and used multiple times" (Wikipedia, 2010).

A battery consists of a number of voltaic cells; each voltaic cell consists of two half cells (the terminals) connected in series by a conductive electrolyte containing anions and cations. *"In the redox reaction that powers the battery, reduction (addition of electrons) occurs to cations at the cathode, while oxidation (removal of electrons) occurs to anions at the anode" (Wikipedia, 2010)*. This means electrons collect on the negative terminal of the battery, and when connecting some type of load (electric motor, smartphone) in between by electrically conductive wire, electrons will flow from the negative to the positive terminal. During discharge the flow of electrons create an electric current that powers the electric component (electric motor, smartphone) of choosing, while the electrolyte conducts positive current in the form of positive ions.

In the SMDLP two batteries, both rechargeable, are used; one for powering the electric motor of the lock and one for powering the smartphone. There are many types of batteries available, all having their own advantages and disadvantaged, and for the sake of good performance it should be decided which type of battery has to be selected for each purpose.

In case of powering the electric motor of the lock as described in section 1.1.2.2 the use of a Nickel-Metal Hydride (NiMH) battery might be favourable. A NiMH battery is a type of rechargeable battery similar to a nickel-cadmium (NiCd) battery but without the expensive and environmentally unfriendly metal cadmium. NiMH batteries tend to have a higher capacity than NiCd batteries and suffer far less from the memory effect. However, when compared with lithium ion (Li-ion) batteries they have a lower energy density and a higher discharge rate. When considering cost price the NiMH battery is the cheaper alternative in comparison with Li-ion batteries. NiMH battery uses a hydrogen-absorbing alloy for the negative electrode, and the positive electrode is nickel-oxy-hydroxide (NiOOH). The positive and negative electrodes are isolated from each other by a separator and are rolled in a spiral shape inside the case. The overall chemical reaction that occurs in a NiMH battery is: $M + Ni(OH)_2 + H_2O \Leftrightarrow MH + (\beta\text{–}NiOOH \bullet H_2O)$. The reaction goes from the left to the right when being charged and from the right to the left when being discharged. This chemical reaction creates a typical nominal cell voltage of 1.2V while discharging. This energy can be used to power the 12V electric motor when 10 cells are put in a serial arrangement or when a power transformer is applied. In the SMDLP system the recharge of the NiMH battery pack is dependent on human movement; with the use of a dynamo the rotary vehicle wheel movement will partly converted in electric power for recharging. NiMH batteries have a relatively high self discharge rate of 30% or more per month, but this does not seem to be any problem in this occasion because it is assumed the SMDLP vehicle will be used multiple times a day ensuring recharge by the dynamo.



In case of powering smartphones Li-ion batteries are used, due to their high energy density as mentioned earlier. Because of this lightness and high energy density Li-ion batteries are ideal for smartphones; in fact they are one of the most popular for all kind of portable electronics. In addition Li-ion batteries have no memory effect, do not use poisonous metals and their self discharge rate is only approximately 5% per month. The only downside they have is that they are relatively expensive.

In Li-ion internal design the anode is made of carbon, the cathode is a metal-oxide and the electrolyte is lithium salt in an organic solvent. During discharge lithium ions carry the current while moving from the negative to the positive electrode, and the reverse occurs when charging. The overall chemical reaction that occurs in a Li-ion battery is: $LiCoO_2 + C_6 \Leftrightarrow Li_{1-x}CoO_2 + C_6Lx$. The reaction goes from the left to the right when being charged and from the right to the left when being discharged. This chemical reaction creates a typical nominal cell voltage of 3.6V while discharging. To enable recharge an external power source has to apply a higher voltage (4.2V) than that produced by the battery (3.6V), forcing the current to pass in the reverse direction; the lithium ions then migrate from the positive to the negative electrode.

One of the downsides of Li-ion batteries is that they develop increased internal resistance over time, which decreases their ability to deliver current. They irreversibly lose approximately 20% capacity per year from the time they are manufactured, even when unused. Another downside is that Li-ion batteries are vulnerable to a number of potential problems, including overheating at the anode, and oxygen production due to overcharging at the cathode. In addition lithium itself is very reactive and might cause explosion. Li-ion cells therefore have build-in protective electronics and/or fuses for ensuring safety. Such a safety circuit in general prevents overdischarging, overcharging and overcurrent and consist of the following according Panasonic:

- ***The Controller IC*** *– The controller IC measures the voltage for each cell (or for each parallel battery block) and shuts off a control switch to either prevent overcharging or to prevent overdischarging. Moreover, the voltage of the control switch is measured on both ends and in order to prevent overcurrent, both control switches are shut off if the voltage exceeds specifications.*
- ***The Control Switches*** *– The control switches turn off the charge or discharge depending on the output of the controller IC.*

- ***The Temperature Fuse*** *– If the control switches experience abnormal heating, this fuse cuts off the current (non-restoring).*
- ***The Thermistors*** *– The thermistors are included in order to accurately measure the battery temperature within the lithium ion battery packs. The battery or charger measures the resistance value of the thermistor between the T-terminal and the negative terminal and during the charging process, controls the charge current along with controlling until the charge is terminated.*

1.1.2.5 Displays

• Smartphone display – *visualise information in an interactive way.*

The smartphone's display is the output device for presenting information in the SMDLP system; it visualises the information in such a way a user can understand and interact with it. The display of the iPhone 3Gs makes this interaction quite intuitive by combining user input with the visual output in its multi-touch screen.

Beside that the display also responds to three other sensors. *"A proximity sensor deactivates the display and touch-screen when the device is brought near the face during a call. This is done to save battery power and to prevent inadvertent inputs from the user's face and ears. An ambient light sensor adjusts the display brightness which in turn saves battery power. A 3-axis accelerometer senses the orientation of the phone and changes the screen accordingly, allowing the user to easily switch between portrait and landscape mode" (Wikipedia, 2010).*

In order to detect a person's input the iPhone multi-touch display uses sensors and circuitry for monitoring changes in electrical current. The screen uses a layer of capacitive material to hold an electrical charge; touching the screen changes the amount of charge at a specific point of contact. The iPhone's capacitors are arranged according to a coordinate system; its circuitry can sense changes at each point along the grid. *"In other words, every point on the grid generates its own signal when touched and relays that signal to the iPhone's processor. This allows the phone to determine the location and movement of simultaneous touches in multiple locations. Because of its reliance on this capacitive material, the iPhone works only if you touch it with your fingertip" (Wilson, 2008)*. This enables to touch multiple points on the screen and this type of screen is able to respond to both touch points and their movements simultaneously. Multi-touch takes things further by allowing gestures at multiple points to affect controls like zoom or scrolling without the need for sliders or zoom buttons or anything of that nature.

The iPhone 3Gs uses a 3.5inch LCD (Liquid Crystal Display) with 320x480 pixels at 160ppi for visualising purposes. Liquid Crystal Displays are very common in mobile electronics (smartphone in this case) because they offer some real advantages over other display technologies; they are relatively thin, lightweight and energy efficient. LCD uses the light modulating properties of liquid crystals; this is based on the effect that the liquid crystal is displayed in a position to rotate polarization of light when an electrical voltage is put. The liquid crystals do not emit light themselves and LCDs therefore need a light source (backlight, sunlight), this is why LCDs are classified as passive displays. The iPhone uses both light sources, is has a backlight for emitting light and an integrated mirror for reflecting sunlight, this combination makes this display transflective. The liquid crystal consists of rod-shaped complex molecules that interact in a helical structure. Naturally they are twisted but when applying an electric current to these liquid crystals they will untwist in varying degrees, depending on the current's voltage. By controlling the voltage applied across the liquid crystal layer in each pixel, light can be allowed to pass through in varying amounts thus constituting different levels of gray. In the iPhone's colour LCD each individual pixel is divided into three cells, or subpixels, which are coloured red, green, and blue. To generate a high number of colours per pixel the levels of grey (256 shades of red x 256 shades of green x 256 shades of blue) are used for mixing colours into a 24-bit palette of 16.8 million colours. In the off-state the iPhone shows a black screen, which means the liquid crystals are twisted and are blocking any light. When turning the iPhone in its on-state it starts to emit light and when also applying current to the liquid crystals they will untwist allowing the light to pass trough.

There is an enormous amount of pixels in the display and in order to control them an active-matrix is used dependent on Thin Film Transistors (TFT). *"To address a particular pixel, the proper row is switched on, and then a charge is sent down the correct column. Since all of the other rows that the column intersects are turned off, only the capacitor at the designated pixel receives a charge. The capacitor is able to hold the charge until* *the next refresh cycle. And if we carefully control the amount of voltage supplied to a crystal, we can make it untwist only enough to allow some light through"* (Tyson, 2009). In this way pixels can be controlled individually; they can be put on or off separately and this process is controlled by a chip.

1.1.2.6 Data transfer

• Wireless – (RFID, NFC, GSM/UMTS and GPS)

• Optical – (Internet)

• Electric conduction – (Hardware like microprocessor and Integrated Circuits)

The data transfers in the SMDLP system are achieved by various transmission media; such as copper wires, optical fibres and wireless communication. The data itself is represented as an electro-magnetic signal, such as an electrical voltage signal or a radiowave signal.

Wireless
In various occasions in the SMDLP system wireless data transferring is used in order to send and receive information. When transferring data from a RFID-tag to reader, as similar with NFC, GSM and GPS technology or any other way of wireless data transmission; electromagnetic (radio) waves are used to communicate. In section 1.1.2.1 wireless techniques like RFID and NFC already were addressed. In the following the focus is on wireless data transmission in general and an example of how to use this wireless technique in the SMDLP system will be given by explaining GPS and GSM/UMTS.

A radio wave is an electromagnetic wave propagated by an antenna. When current enters the antenna, it does create a magnetic field around the antenna. In space, the magnetic field created by the antenna induces an electric field in space. These electric and magnetic fields (electromagnetic fields) induce each other repeatedly in space at the speed of light, travelling outward away from the antenna. "*The electric and magnetic fields are considered together as the two components of an electromagnetic wave"* *(WHO, undated)*. In ***wireless data transmission*** a transmitter takes some sort of message, encodes it into a sine wave and transmits it with radio waves. A receiver receives the radio waves and decodes the message from the sine wave. *"Both the transmitter and receiver use antennas to radiate and capture the radio signal"* *(Brain, 2000)*.

In the SMDLP system a smartphone will be equipped with a ***GPS*** receiver to enable location tracking. The Global Positioning System (GPS) uses high-frequency, low-power radio signals from the GPS satellites to communicate with receivers. *"There are currently 27 GPS satellites in orbit – 24 are in active use and 3 act as a backup in case another satellite fails"* *(Wilson, 2005)*. *"The orbits are arranged so that at any time, anywhere on Earth, there are at least four satellites 'visible' in the sky"* *(Brain and Harris, undated)*. The GPS receiver in the smartphone has to locate four or more of these satellites, figure out the distance to each, and use this information to deduce its own location. *"This operation is based on a simple mathematical principle called trilateration"* *(Brain and Harris, undated)*. Basically, it draws a sphere around each satellite it can locate. Already in case of contacting three satellites, trilateration makes the three correlating spheres intersect in two points – one is in space, and one is on the ground. *"The point on the ground at which the three spheres intersect is your location"* *(Wilson, 2005)*, the fourth or more satellites are used for accuracy reasons.

Essential for this GPS location tracking technology is the receiver figuring out how far the satellite's signal has travelled by timing how long it took the signal to arrive. *"In order to make this measurement, the receiver and satellite both need clocks that can be synchronized down to the nanosecond"* *(Brain and Harris, undated)*. Every satellite contains an expensive atomic clock, but the receiver itself uses an ordinary quartz clock. The receiver constantly resets its clock to be in sync with the satellite's atomic clock by using the incoming time signals from four or more satellites, and gauges its own inaccuracy. *"At a particular time (let's say midnight), the satellite begins transmitting a long, digital pattern called a pseudo-random code. The receiver begins running the same digital pattern also exactly at midnight. When the satellite's signal reaches the receiver, its transmission of the pattern will lag a bit behind the receiver's playing of the pattern"* *(Brain and Harris, undated)*. The length of the delay is equal to the signal's travel time, and when this time is multiplied by the speed of light the travelled distance can be determined.

Due to this wireless data transfer abilities in combination with embedded software in the smartphone and the presence of actual maps (Google maps for instance) the location data tracked by GPS, can be visualised in an interactive and useful way towards its user. In the SMDLP system GPS will mainly allow user to search for vehicles, allow the supermarket to track all customers making use of the system and monitor the total fleet of vehicle, and notify any user when leaving a designated area.

"Smartphones use cell-phone network technology to send and receive data (such as phone calls, web browsing, file transfers, etc.)" (Coustan and Strickland, undated). Phones can communicate in a cellular GSM network by contacting the nearest cell, and they can switch cells as they move around. Base stations (tower with radio equipment) are the centre of such a cell; they transmit radio waves over an area of 26 square kilometres approximately while they are arranged in a typical hexagonal grid. Each cell (of the seven on a hexagonal grid) is using one-seventh of the available radio channels so it has a unique set of frequencies to prevent collisions in data transfer. In order to transfer bigger amounts of data smartphones use 3G (third generation) technology such as UMTS for high speed data transferring up to 3Mbps instead of the GSM standard. Most smartphones in Europe are hybrids; making use of both GSM and UMTS, allowing seamless dual-mode operation. UMTS initially used the 2.0-2.15GHz frequency band, but in order to speed up implementation it was decided to also use the 900MHz and 1800MHz band initially intended for GSM only. The compatibility of a smartphone with GSM and UMTS makes it possible to download information from the Internet and send and receive large multi-media files beside the standard voice calls.

Optical

The connection of the smartphone with the Internet is very important in the SMDLP system. Potential users can register on the Internet via a smartphone application, and the SMDLP vehicle rental system is also monitored and managed with use of the Internet. The Internet therefore is an important network in order to send and receive information while making use of SMDLP vehicles. In a part of the Internet network, information is transferred trough optical grass fibre wires. In optical internet cables light travels trough the optical fibre by making use of reflections inside the cable, sending a signal with the speed of light. In the SMDLP system a server is attached to this network, able to collect data about vehicle location, user information and the time span a vehicle is used. On the other hand the server uses the Internet to send information about locations where SMDLP vehicles are parked, and after an authentication process the server also sends activation codes to enable usage.

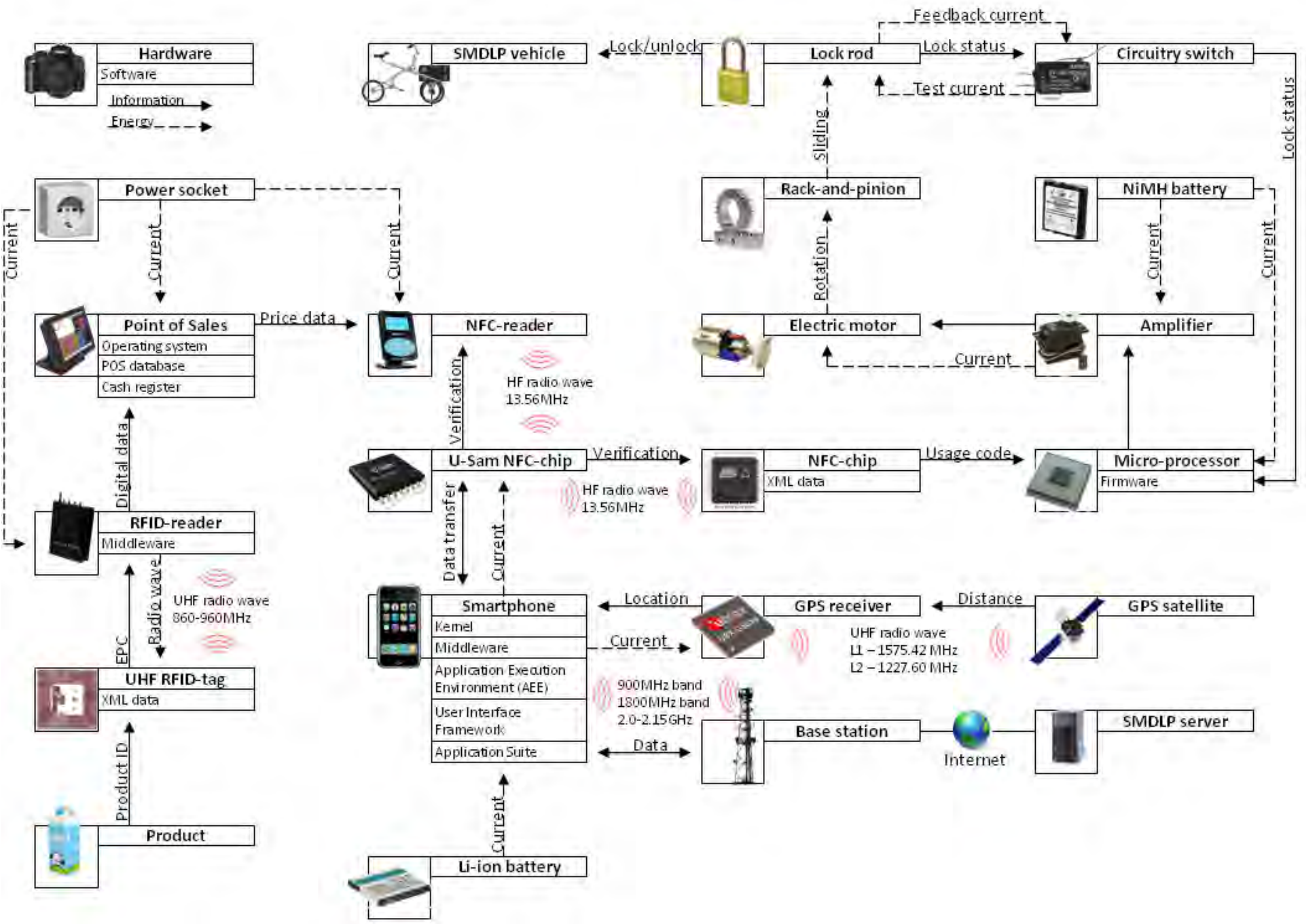
Electric conduction

On a component level data transfer is possible due to a phenomenon called electric conduction. *"Electrical conduction is the movement of electrically charged particles through a transmission medium (electrical conductor)" (Wikipedia, 2010)*. In electronics these electrical conductors are most often some sort of metals and the electric current is carried by electrons. In metals, this ability is due to the 'loose' binding of the outer electrons in the electron shell, so that in practice the metal atoms are embedded and some of the electrons can move trough the material. The physical parameters governing this transport depend upon the material;

some of the most common metals used for electric conduction purposes in electronic are copper, silver and gold.

In a micro-processor for instance gold is used in its hair-thin circuits because of its resistance to corrosion, and excellence in conducting electricity. Gold is also used in telephones, and helps change vocal vibrations into electric currents. In the SMDLP system also copper is used in plenty occasions, for instance in the RFID-tags and the electric motor were it is used in order to convert electro-magnetic radiation into electric current and vice versa. This is due to its conductive properties in combination with the structure the material is put into (wired coils).

1.1.3 Product model



In the block diagram above the overall system is displayed, but one should notice the smartphone is in the middle of the two separate, independent systems (payment system at the left and rental system at the right). The block diagram is a visual summary of all previous described components, the technologies they are based upon and how they are implemented in the SMDLP system. The diagram shows blocks (hardware, software and a picture of the component) and the flow of information and energy between them. This diagram should be considered as an abstract way of explaining the SMDLP system, only information that was considered 'meaningful' is visualised. This means additional, very detailed information about software in the SMDLP server, the software in the GPS satellite and all information stations of the Internet for instance, are not considered 'meaningful' for this specific SMDLP system. In other words; they are important, but do not have a mayor contribution in explaining how the SMDLP system should operate.

Both systems make use of quite advanced technologies; this means quite large investments are needed in order to implement such a system in total. This might be a barrier for supermarkets for instance. Therefore they can also decide to keep use of the current barcode based payment system for instance in combination with the proposed rental system. In terms of providing the most benefits for the users (the supermarket's customers) it is favourable to implement the total system of course.

1.1.4 Product redesign / improvements

In this product redesign the focus will be on making the SMDLP rental system more theft and vandalism proof. The initial proposal for the locking mechanism will be improved by combining it with the energy providing module, and integrate this combination at the rear hub of the vehicle. From the product model (section 1.1.3) one could see that the smartphone already has a GPS receiver, therefore in 'normal' usage an additional GPS receiver embedded in the vehicle itself was not necessary for tracking the vehicle's location.

Speaking about possible 'abnormal' behaviour of malicious people (theft and vandalism) the SMDLP vehicle should be better protected. To do so, the U-bar lock as described in section 1.1.2.2 will be replaced by a more advanced protection module. This protection module (as displayed in the picture below) consist of a (1) cable lock which is integrated in the vehicle's frame, (2) an accelerometer for impact (shock/vibration) detection and tilt detection, and (3) an alarm speaker for sending out an 100DB siren when 'abnormal' behaviour is detected.

The cable lock runs trough the frame, and is an essential part of the lock status circuitry. When the cable lock's plug is connected to the rear hub-axle the electric circuit is closed, but when broken without allowance of the SMDLP server a siren will sound. Because the cable lock is attached to the rear hub-axle (shielding the axle nut) it is impossible to take the rear wheel out, without breaking the circuit. Taking the rear wheel out, is a stupid idea anyway because the vehicle uses a shaft drive, this makes it very hard for a thief to make the vehicle function again when once broken.

The three-axis accelerometer is very important for detecting theft and vandalism, because it can sense impact (when someone is hitting/kicking the vehicle) and tilting (someone lifting, turning or flipping over the vehicle). The SMDLP server can activate and deactivate the alarm trough a user's smartphone, this is necessary because the alarm should not sound when detecting shocks during riding in 'normal' usage. The 'normal' usage can be indicated by the system as follows: (1) a user is given approval for usage by the SMDLP server, and (2) the rear wheel is spinning, these restrictions are programmed into the micro-processor. With applying these two restrictions it may be assumed a vandal will not destroy the vehicle while indentifying to the SMDLP server and spinning the rear wheel as well. Sensing whether the rear wheel is spinning is possible because the smarthub module uses an internal hub dynamo. This dynamo generates current when spinning; this current is used for charging the NiMH battery, but can also be used as a signal to the micro-processor for indicating wheels are spinning.

At the rear wheel, between the smarthub module and the protection module, a communication module is situated. This module embeds the NFC-chip, GPS-receiver, micro-processor and the lock status circuitry. The communication module has a circular plastic housing, allowing the NFC and GPS antennas to send and receive signals without disturbance. After usage the customer can only 'return' the vehicle when the cable lock is attached to the rear hub-axle again, restoring/closing the lock status circuit.

The smarthub module is considered to be ´smart´ because it can generate current and has an internal locking mechanism, based on GPS technology, preventing users to leave the designated area of usage. The so called hub lock has an integrated electric motor that will build up resistance when leaving the designated area, making it harder for a user to pedal. The hub lock will slow down the vehicle at first (at this moment the user will receive a notification message on the smartphone) and will block the hub totally in the end when notification is ignored and GPS senses the vehicle is too far away from the designated usage area.

In bullet points:
• Vehicle is locked by cable lock, which will sound an alarm when broken.
• Vehicle will lock itself when leaving a designated area.
• Accelerometer will detect impact and tilting and will sound an alarm.
• Users can unlock the vehicle only by NFC.
• The SMDLP will always know were the vehicle is due to GPS.

References

BAKAS, A., 2010. *Trendrapport 2010* [online] Bakas Trendwatcher.
http://www.bakas.nl/persberichten/pdf/Trendrapport2010.pdf [Accessed 12-04-2010].

BRAIN, M. 2003. *How Electric Motors Work* [online] HowStuffWorks.
http://www.howstuffworks.com/motor.htm [Accessed 18-05-2010].

BRAIN, M., 2000. *Sending and Receiving: Radio Waves* [online] HowStuffWorks, published in the Smart Systems & Technologies Reader of April 2009. http://electronics.howstuffworks.com/radio.htm

BRAIN, M. and HARRIS, T., undated. *How GPS Receivers Work* [online] HowStuffWorks.
http://electronics.howstuffworks.com/gadgets/travel/gps.htm [Accessed 12-05-2010].

BONSOR, K. and KEENER, C., 2007. *How RFID Works* [online] HowStuffWorks.
http://electronics.howstuffworks.com/gadgets/high-tech-gadgets/rfid.htm [Accessed 14-04-2010].

CLARK, S., 2009. Sony/NXP joint venture announces 'universal NFC chip' [online] NFC World.
http://www.nearfieldcommunicationsworld.com/2009/02/09/3763/sonynxp-joint-venture-announces-universal-nfc-chip/ [Accessed 13-05-2010].

COUSTAN, D. and STRICKLAND, J., undated. *How Smartphones Work* [online] HowStuffWorks.
http://communication.howstuffworks.com/smartphone.htm [Accessed 20-05-2010].

DANNENFELDT, D., 2008. *How Cellular Electronic Payments Work* [online] HowStuffWorks.
http://communication.howstuffworks.com/cellular-electronic-payment.htm [Accessed 14-04-2010].

GRABIANOWSKI, E., undated. *How Blink Technology Works* [online] HowStuffWorks.
http://money.howstuffworks.com/personal-finance/debt-management/blink.htm [Accessed 14-04-2010].

LAYTON, J., 2007. *Can you use a cell phone as a credit card?* [online] HowStuffWorks.
http://electronics.howstuffworks.com/nfc-phone.htm [Accessed 14-04-2010].
NICE, K., undated. *How Power Door Locks Work* [online] HowStuffWorks.
http://www.howstuffworks.com/power-door-lock.htm [Accessed 13-05-2010]

QUICK, D., 2010. *Hidden RFID tags could mean end of bar-codes and lines at the checkout* [online] Gizmag.
http://www.gizmag.com/nano-based-rfid-tag/14565/ [Accessed 16-04-2010].

RFID JOURNAL, 2003. 1-Cent RFID Tags for Supermarkets [online] RFID Journal.
http://www.rfidjournal.com/article/view/363 [Accessed 13-05-2010].

STRICKLAND, J., 2009. *How can I unlock my front door when I'm out of town?* [online] HowStuffWorks.
http://electronics.howstuffworks.com/gadgets/home/unlock-front-door-remotely.htm [Accessed 14-04-2010]

TYSON, J., 2009. *How LCDs Work* [online] HowstuffWorks.
http://www.howstuffworks.com/lcd.htm [Accessed 23-05-2010].

WILSON, T.V., 2005. *How GPS Phones Work* [online] HowStuffWorks.
http://electronics.howstuffworks.com/gps-phone.htm [Accessed 12-05-2010]

WIKIPEDIA, 2010. [online] Wikipedia, the free Encyclopedia - http://en.wikipedia.org
- Accelerometer
- Augmented reality
- Battery
- Electrical conduction
- Electric motor
- iPhone
- Loyalty program
- Middleware
- Near field communication
- Redox reaction
- Radio-frequency identification
- Social media

WHO, undated. *Electromagnetic Fields* [online] World Health Organisation, published in the Smart Systems & Technologies Reader of April 2009. http://www.who.int/peh-emf/about/WhatisEMF/en/print.html

ZEBRA, 2009. An Introduction to Passive RFID [online] ZIH Corp.
http://www.zebra.com/id/zebra/na/en/documentlibrary/whitepapers/an_introduction_to_passive_rfid.File.tmp/WP_P1014577_RFID.pdf [Accessed 13-05-2010].

ZWEERS, A. and VAN LEEUWEN, R., 2010. Tien technieken die de wereld veranderen [online] MT Management Team.
http://www.mt.nl/1/15414/home/tien-technieken-die-de-wereld-veranderen.html [Accessed 16-04-2010].