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Wheelchair-bicycle Mechanical Coupling

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INDEX

1. ABSTRACT

Nowadays around the 15 per cent of the world’s population, which is a billion of people approximately, suffers some kind disability according to the United Nations database. Just talking about Denmark, it is possible to find 320.000 people who have some kind of disability and who represented by Disabled People Organizations – Denmark (DPOP) involving 32 different minor organizations.

In view of all mentioned above this report is going to be focused in one of Denmark’s signs of identity: the bicycle. It is completely normal to see people carrying their children with these rickshaws but, couldn’t it be also great to go for a ride with a friend of yours who cannot do it just by his/her own?

With the help of our mechanical and logical knowledge developed along our bachelor studies; some organizations and experts, it will be studied the development of an attaching method for wheelchairs and bicycles. This study involves different ideas for the design, with their correspondent mechanical backup, drawings and specifications.

As basic aspects of this following report, it can appear:

- Mechanical approval and viability of the final design, it has to be as simple as possible.
- Economical design.
- Most adaptable as possible for different types of bicycles and wheelchairs.
- Research and explanation of the methodology to reach it.

2. TITLE PAGE

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3. FOREWORD

Present report is written by Blanca Adiego and Alvaro Sarria, mechanical students from Aarhus School of Engineering, Denmark as bachelor project in summer 2014.

This report is aimed at engineering with interested in mechanical attachments between wheelchairs and bicycles. It contains a previous introduction about wheelchairs and bicycle basic characteristics, as well as the most adequate ones according to the Danish people height average. After that, there is a study about all the possible designs that can fulfill the basic requirements and a decision analysis in order to reach the better solution. Finally, the report explains the characteristics and items than contribute to that final solution.

During this project, there is people that is necessary to thank because of their help, support and knowledge provided to the project.

> Anders Hvilsted, Civ. ing., HD(R), Aarhus University, School of Engineering, for supervision and help through all the project.

4. READING GUIDELINE

This report can be easily divided in several parts:

- Investigation and research about all different possibilities for reach the aim of the project.
- Selection process in order to get the best solution.
- Development of that idea.

The background section also contains some information about basic dimensions, shapes and characteristics of urban bicycles and manual wheelchairs. The development part has also an explanation about how to mount and dismount the assembly in the appropriate way.

To the main report belongs and appendix, which is referred to for deeper explanations, calculations and drawings.

All units are marked as follows: [unit], example [N·m].

5. BICYCLES AND WHEELCHAIRS' GENERAL CHARACTERISTICS

This part of the report talks about the general characteristics of the most common bicycles and wheelchairs that can be found in the market, regarding dimensions, particularities, etc. working as an introductory part for the rest of the report.

5.1. WHEELCHAIRS

It is possible to find many different types of wheelchairs, according to the user's needs. Anyway, the most common ones are the manual lightweight ones. This wheelchair is relatively cheap and it offers a huge umbrella of accommodation facilities in order to make the user as much comfortable as possible. It is specially designed for the part of the users that have to spend most of the day in their wheelchair.

The basic wheelchair can be distinguished by the two big rear wheels that are used by the user as propel, the seat and the two smaller wheels that are located in the front part and can rotate and guide the chair. As it can be seen in the figure 5.1, these are the most common parts of a lightweight manual wheelchair.

A : Pushing Handle
B : Back
C : Rear Wheel
D : Pushrim
E : Tiltbrace

F : Front Caster
G : Crossbrace
H : Footrest
I : Seat
J : Armrest

Fig. 5.1. Basic parts of a manual wheelchair.

Nevertheless, it is important to take into account the fact that every different user has different needs. That is because it is possible to find infinity of choices according to different kind of disability, weight and body dimensions, etc. As it was mentioned before, the right choice is one of the most important issues that the user has to be completely aware of. There are some basic measurements that complete define the wheelchair structure.

In the first place, the wheelchair seat width. It is the distance between the widest point between the hips and knees when seating in a comfortable way and add 2,5 [cm]. The common sizes are 16[”] (or 40,64 [cm]), 18[”] (or 45,7 [cm]) and 20[”] (or 50,8 [cm]). To get the overall width it is only necessary to add the wheels breadth.

Secondly, it is the seat depth. It is measured from the back of the user’s pelvis to the back of their shins, taking into account that they are considered sitting with the legs dropping at 90 degrees from their knees minus 2,5 [cm]. To get the overall depth, it is necessary to add the handles’ length.

Then, it is found the seat height that it is important to be considered regarding to make it easier for the user to reach tables, toilets, beds, etc.

And finally it is the back height. It varies from user to user depending on their degree of disability. People with good upper body control can get lower back height. On the contrary, people with more reduced mobility can get a back height as high as their shoulders, if needed. Here in figure 5.2., are shown the basic measurements that have to be known to choose the appropriate wheelchair.

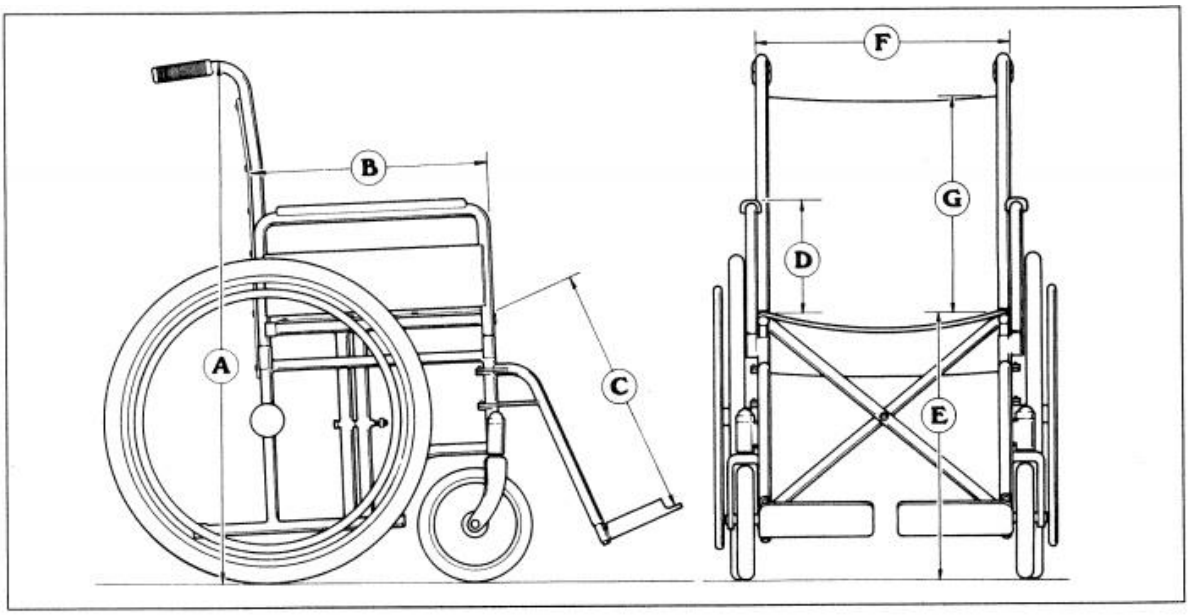


Figure 5.2. Different view of a manual wheelchair.

- A: Overall height.
- B: Seat depth.
- C: Footrest support
- D: Armrest height.
- E: Seat height.
- F: Seat and back width.
- G: Back height.

Heights from floor	**Width**	**Depth**	**Designation**
49,53	25,4	20,32	Pre-school or tiny tot
49,53	30,48	25,4-29,21	Child’s or tot’s, high
41,91	30,48	25,4-29,21	Child’s or tot’s, low
53,34	35,56-26,83	29,21	Growing chair
44,45-52,07	35,56-40,64	27,94-33,02	Growing chair
46,99	40,64	35,56	Junior or slim adult
49,53	40,64-41,91	40,64-43,18	Narrow adult
49,53-52,07	45,72	40,64	Adult
		43,18	Tall adult
49,53-52,07	50,8-55,88	40,64	Wide adult

Table 5.1..Dimensions according user. (Dimensions in [cm])

Moreover, standard adults wheelchair normally have rear wheels of 24[”], or 60,96 [cm] and they can be made of pneumatic or semi-pneumatic solid, according which are their main purposes.

Regarding all collected data, it has come to the conclusion that the study will be based as reference on average adults’ wheelchair with a 24[”] in wheels to get a reference point.

5.2. BICYCLES

It is said that the variety of wheelchairs that are available in the market is huge but it has nothing to do with the amount of different bicycles developed all over the years.

In order to be able to choose an appropriate bicycle it is worthy to know that their dimensions are ruled by the anthropometric dimensions of the human body and they can be put into different size groups.

For this certain study, the height average of Danish men and women will be taken as reference measurements. According to statistics, the male people in Denmark have a height average of 180’60 [cm] in contrast with the women who reach 168 [cm]. With this information it is possible to calculate the characteristics dimensions for both genders multiplying the average height per the characteristic anthropometric factors showed in the figure 5.3. below:

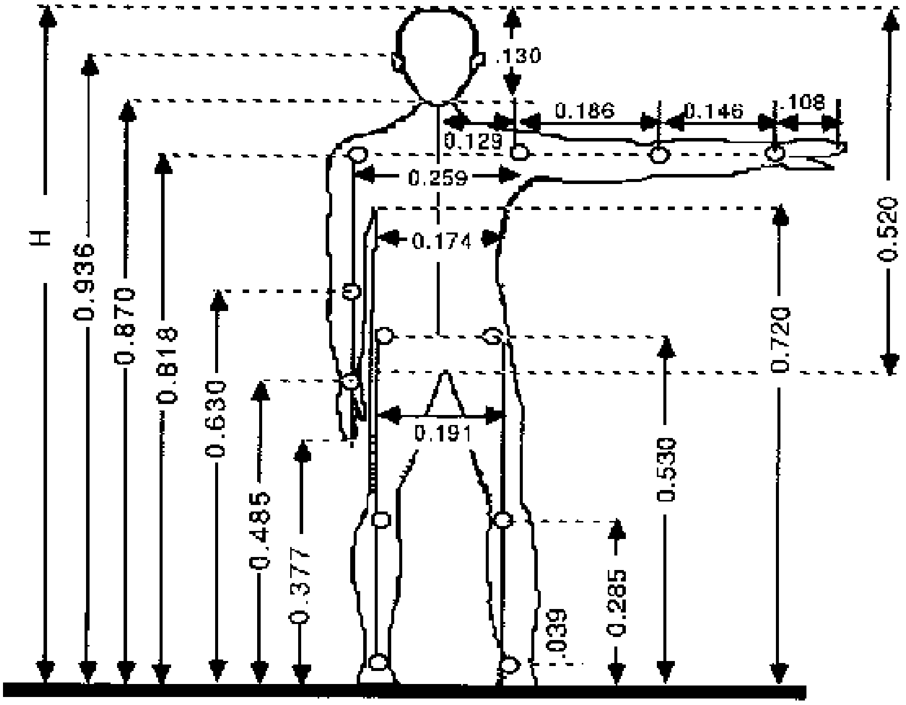


Fig. 5.3. Anthropomorphic human body coefficients.

And for having an approximate idea for both women and men’s characteristic dimensions which rule the common bicycles’ dimensions, we can put them in a table (table 5.2.) to make it easier their comparison.

	MEN DIMENSIONS [cm]	WOMEN DIMENSIONS [cm]
Inner thigh	180,60 x 0,485 = 87,6	168 x 0,485 = 81,5
Shoulders	180,60 x 0,259 = 46,8	168 x 0,259 = 43,5
Arm	180,60 x (0,186+0,146+0,108) = 79,5	168 x (0,186+0,146+0,108) = 74
Forearm	180,60 x (0,146+0,108) = 45,9	168 x (0,146+0,108) = 42,7
Thigh	180,60 x (0,530-0,285) = 44,3	168 x (0,530-0,285) = 41,2
Leg	180,60 x 0,285 = 51,5	168 x 0.285 = 47,9

Table 5.2. Danish women and women dimensions.

Once that the characteristic dimensions are known, it is possible to measure the appropriate size for the bicycle. But, in the first time, it is mandatory to divide the bicycles variety into three main groups: mountain bikes, urban bikes and road bikes.

However, this device is thought to be used in urban zones, such as parks and paths, it is only considered the urban model, both men and women models. The most common measurements of bicycle frame according to Danish averages, measurement from table 5.2., are:

MEN:

Urban size: 56,9 [cm].

WOMEN:

Urban size: 56,1 [cm].

Figure 5.4. Men Bicycle dimensions.

Figure 5.5. Women bicycle dimensions.

5.3. CONCLUSION

Until this moment, there has been developed an explanation about general characteristics from bicycles and wheelchairs. As it has been seen, in a first view, it is impossible to build a device that can join every different kind of wheelchair to every different type of bicycle. Due to that, the research is focused on new non-foldable wheelchairs, as the one that was donated by Guldmann interprise, and urban bicycles (these characteristics can be deeply checked on Appendix 2).

Another issue involves which are the most optimum points to do the attachment. Even if the research is enclosed to a certain type of bicycles and wheelchairs, they have plenty of different characteristics. One of the bases of the attachment is to find the common points.

On the other hand, it is also necessary to check the structure characteristics of both devices in order to know if they will stand different stresses that appear due to motion or just due to the users’ weights.

According to that, there are being developed some design ideas that could fulfill the requirements. After a deeper study, it will be chosen one among the others and that will be further developed.

6. DRAFT OF IDEAS

This chapter of the report explains briefly the different ideas that has been developed during a brainstorming that could solve the problem that is being studied. Nevertheless, further information can be found in Appendix 3.

There are a total of 14 different solutions and sub-solutions which are shown in figure 6.1. It is possible to easily recognize four main groups which each one differs from the other in which part of the bicycle it is located the wheelchair’s adaptor; it is a trailer or the wheelchair itself. As it is, it is feasible to find “Trailer”, “Front part location”, “Back part location” and “Sidecar”.

The 15 different initial solutions and sub-solutions are showed in the figure 6.1. in a basic conceptual maps, divided in four groups, previously named.

1. TRAILERS

2. FRONT PART LOCATION

3. BACK PART LOCATION

4. SIDECARS

Figure 6.1. Graphic resume of ideas in their different groups.

7. SELECTION PROCESS

This part of the research is completely essential when after a brainstorming it is necessary to choose the best possible option among the other ones.

Some basic criteria such as functionality, handling, daily use aptitudes, etc. are defined at the beginning as requirements according to the final product expectations. There are four main groups in the study and each solution and sub-solution has to be measured and classified according to its grade of achievement in every required property. After that and taking into account all the gathered information, it is possible to reach to the best option and get deeper into it.

It is being developed a mechanical project which is focused in the tandem riding adaptation system for disabled people. Because of that, both users - wheelchair and bicycle - have to be the basis for choosing decisions, as in every project the stakeholders play a really important role during the development. Security, simplicity, adaptability and comfort are the most important properties that the buyer will be taken into account at the time of the sale. These two principal characteristics will involve such different ones as functionality, prize or maintenance which are also factors that will affect the final choice.

Reached to the point that there are a lot of different alternatives that can fulfill initially the requirements, they are going to be measured according to the criteria following the Multi-Criteria Decision Analysis (MCDA).

Of course not all the criterion has the same weight in the final result and that is because this method is chosen. In the first place, the relevant criteria have to be identified and perfectly defined according to considerations relevant to the decision that has to be made. Once it is clear, each criterion is weighted to reflect the relative importance in accordance with the decision-making body perspective.

In the mathematical way, the final operation to calculate the importance of each alternative,Ai, according to each criterion, Cj, it is reduced to:

$$A_i^{SCORE} = \sum_{j=1}^{n} w_j \cdot a_{ij} \; for \; a = 1,2,3,..n. \qquad (7.1)$$

Where:

- w_j : Relative weight of the importance of the criterion Cj.
- a_{ij}: Performance value of the alternative Ai.
- n: Number of decision criteria.

It can be found a division of eight groups of main criterions, divided in different sub-criteria (some of them, that will determinate the best choice between the different designs presented in this report. The following are:

1. Use:

These criteria are divided in three more sub-criteria. The objective of all of these is to measure up and evaluate the different aspects about the daily use of the device in a separate way.

- Practicality.

It is evaluated the simplicity of the mechanism and the facility that the user has for adapt him/herself to it.

- Social aptitudes.

It is the device's capacity to maximize the social interaction between the driver and the passenger, being 10 the most and 0 the lowest.

- Transportation & Storage.

In these sub-criteria is considered the ease to moving the whole apparatus in case the owners had to go to somewhere or just it keep it somewhere.

2. Functionality:

The aspects of the device's functions will be analyzed in this headland. The criteria are distributed in 4 more sub-criteria to try to cover all the range of aspects about the functionality.

- Size.

Depending on the size of the mechanism the user will have more or less troubles in managing it (as well as for riding at the road and for manipulating it).

- Assembly.

The assembly of the device is an important thing to take into account. The easier to mount it, the more comfortable will be for the user.

- Adaptability/versatility.

Considering that the device is adapted to the bike in different ways depending of the model, this criteria will prioritize that ones that its adaptation is better than the rest, it is it can cover a larger number of wheelchairs and bicycles.

- Number of pieces.

Directly related with the assembly and the transport sub-criteria. A less number of pieces will mean a simpler model. Evaluated with a 10 as the less number of parts and 0 as the most.

- Stability.

Depending on how is the device assembled to the bike due to its shape, the whole will have more or less stability. This sub-criteria will measure up that being 10 the most and 0 the less.

- Adaptable for electric bicycles.

As this device is designed for disabled people transportation, it can be an extra help to have a motor in some uphill paths, after a long ride, etc. This aspect will be count only as an extra point, so to the final mark it will be add 0.5 points if it also adaptable to this kind of bicycles.

3. Handling:

In this part of the criteria all the physical aspects of the all different designs will be studied one per one to find out the most simple and efficient model, it is specially referred to movement situation.

- Steering.

The facility in driving the whole is pretty important for the design’s choice, so it will be given priority to those designs with an easier way to drive.

- Weight.

It is tried to develop a device able to be used in the simplest and easiest way so the heavier the mechanism, the more difficult to handle will be.

- Force distribution.

Important aspect that must be taken into account as depending on the distribution of the forces applied on the mechanism, it will move in an easier or more difficult way.

4. Maintenance:

Facing the cares that the models must have, the different ways to have the model ready for its use will be analyzed in this point.

- Standard maintenance.

Everybody should check out often the state of its device, so depending on the way that it must be done the costumer will have more or less difficulties. In this sub-criteria it will prioritize the less number of problems that the device maintenance can suppose.

- Expectation until first failure.

A major number of pieces, different types of materials or different attachment methods can vary the expected time of correct behavior until failure. According to that it is possible to expect a certain amount of time until failure; it is set 0 as shortest and 10 as longest.

- Maintenance time.

These sub-criteria are completely in relation with the two above. Larger number of pieces, complicate attachment methods, etc will increase the time that the device has to be in repair workshop.

5. Price:

As in every item we are looking for, its price is one of the main reasons that we consider before buying. In these criteria we analyze the different economical balances that the different devices suppose.

- Production.

Derives expenses from the different mechanical operations required for the construction of the device parts.

- Materials

Generated expenses by the purchase of materials for the different devices.

- Logistics

Derived expenses from the transfer, shipping and storage of the devices parts or the whole device.

6. Innovation:

In these sub-criteria it is important to define what it innovation is talking about the final product. It can be measured according the sentence: “What has been done before?” or “Is it usual to see it on the streets?” New ways of attachment, new materials, shapes, etc. can add points to this category marks.

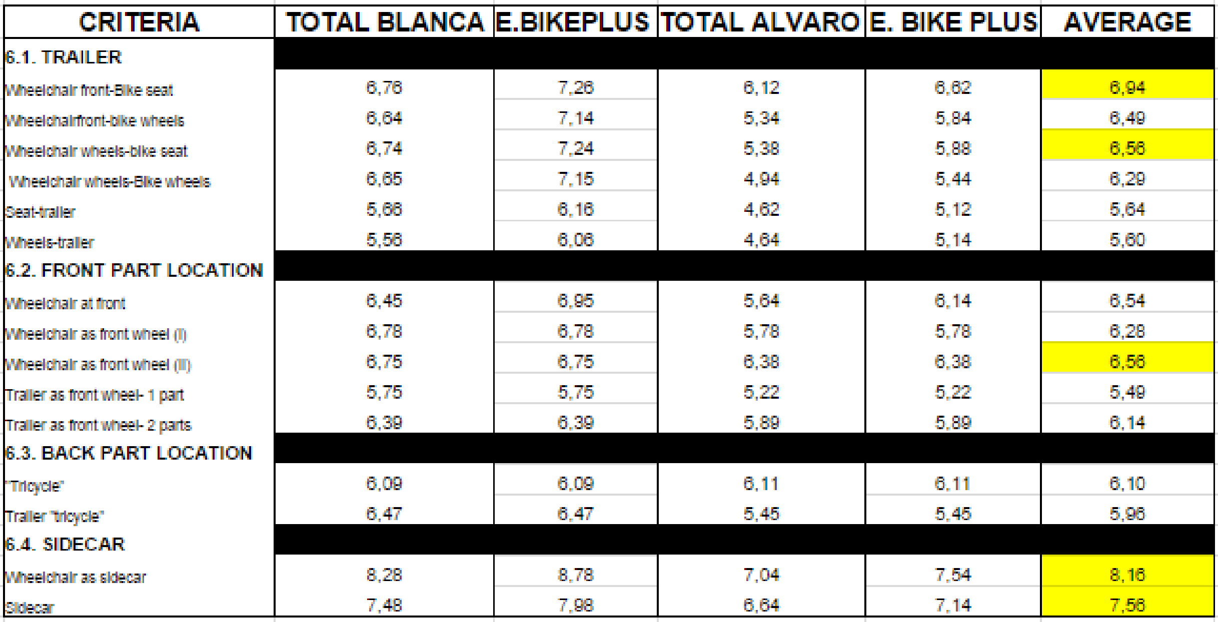
7. Security:

This section refers to the safety both users are feeling. It can be influenced by the own device design (negative effect forces, not optimal structure, etc.) and also for the different security methods installed such belts, clamps, etc.So the more safe is the structure the higher will be the mark of this criteria.

8. Esthetics:

One of the lowest weight criteria of the analysis, we focus this topic on the good looking aspects of the device facing the costumers’ liking.

There has been developed two Multi-criteria decision analysis according to the two designers' points of view, they can be checked on Appendix 3. The result can be seen on the table 7.1., in where the most suitable designs are stood out in yellow.



CRITERIA	TOTAL BLANCA	E.BIKEPLUS	TOTAL ALVARO	E. BIKE PLUS	AVERAGE
6.1. TRAILER					
Wheelchair front-Bike seat	6,76	7,26	6,12	6,62	6,94
Wheelchairfront-bike wheels	6,64	7,14	5,34	5,84	6,49
Wheelchair wheels-bike seat	6,74	7,24	5,38	5,88	6,56
Wheelchair wheels-Bike wheels	6,65	7,15	4,94	5,44	6,29
Seat-trailer	5,66	6,16	4,62	5,12	5,64
Wheels-trailer	5,56	6,06	4,64	5,14	5,60
6.2. FRONT PART LOCATION					
Wheelchair at front	6,45	6,95	5,64	6,14	6,54
Wheelchair as front wheel (I)	6,78	6,78	5,78	5,78	6,28
Wheelchair as front wheel (II)	6,75	6,75	6,38	6,38	6,56
Trailer as front wheel- 1 part	5,75	5,75	5,22	5,22	5,49
Trailer as front wheel- 2 parts	6,39	6,39	5,89	5,89	6,14
6.3. BACK PART LOCATION					
"Tricycle"	6,09	6,09	6,11	6,11	6,10
Trailer "tricycle"	6,47	6,47	5,45	5,45	5,96
6.4. SIDECAR					
Wheelchair as sidecar	8,28	8,78	7,04	7,54	8,16
Sidecar	7,48	7,98	6,64	7,14	7,56

Table 7.1. Results for MCDA.

As it can be seen there a notable difference between the different groups.

In a first view, the less scored one is the "tricycle" group. This group turned to be not such a good idea as it was supposed to be. It gets good grades according to size and steering, but the assembly is so complicated and the necessity of product two different items turns them in a non optimal design.

Secondly, it is the "trailer" group. In general the final score is not as low as it could have been expected. Due to its good functioning proved along the past years. However, they do not get such good results when innovation, size and social aptitudes, which can be considered as main goals of the final design. It is also worthy to say, in this group and in the front location one, that actual trailer designs get less points than the other ones, due to the fact that is not as comfortable to attach a wheelchair to a trailer and then to the bicycle than just attaching the wheelchair to the bicycle.

The front location also got good results in a first analysis but at the end they cannot be stood up because they are not attachable to electric bicycles. This consideration is made due to the fact that the bicycle user will have to carry loads around 100 [kg], so it would be really useful for him/her to get with an extra help.

Finally, the sidecar group got the best marks, specially the one in which the own wheelchair acts as sidecar. This one has been so well scored due to the social aptitudes that this design brings. It is not difficult to steer and size and adaptability are perfect matches with this design. Also the other one got a good score, but is not as well considered when a completely new trailer has to be designed and attached instead of a common wheelchair.

Regarding this MCDA results, it has been reached that the Wheelchair acting as a sidecar is the most suitable design and will be deeply developed in the next chapter.

8. WHEELCHAIR AS SIDECAR

After the Multi-criteria decision analysis has been applied, it has been reached to the conclusion that locating the wheelchair as a sidecar is the most adequate design. This device has been chosen essentially due to its innovative and social aspects. It is really common to see people riding bikes with some kind of passenger or load located in the front or the back parts, but not at all located by one side. Not only that, it is possible to both users to easily communicate with each other, that is one of the main goals of this design, that is initially thought that will be use for comfortable rides in the free time, not for everyday transportation.

When designing, especially a few factors will be taken as principal requirements; those are simplicity, adaptability, social aptitude and security. Because of that, these will be present always as the design keeps going on forwards.

8.1. PROBLEM OVERVIEW AND INITIAL CONSIDERATIONS

The aim of this study is to reach a simple, resistant and affordable way to attach a common manual wheelchair to a bicycle. It is necessary to reach a method or mechanism that allows both devices to ride together. It could seem to be a not a complicate task. Nevertheless, a lot of different parameters and considerations are involved.

A bicycle and a wheelchair are completely different devices. Firstly, the bicycle is an unstable static mechanism that steers due to countersteering, the steering relays on how you turn and incline the front wheel, which acts as a gyroscope. Moreover, it is necessary to take into account the huge amount of different designs that are available in the market nowadays. As it was mentioned, in order to reach a more adequate device, the study will be focused on common urban bicycles. On the other hand, it is the wheelchair. They are specifically designed for being steered by systematic propel of the rear wheels, which attached to one side of the chair and the work separately. It is both statically and dynamically stable and also counts with two caster wheels located in the front that provides stability and helps to the wheelchair steering.

The final attached mechanism turns into a stable device which will be steered by direct steering; it is turning the handlebar in the direction you want to go.

The problem lies in how to attach both devices in order to make it viable for comfortable rides for both users. The bicycle acts as the “powered” part of the assembly that engines and also slows it down, so it will provoke different stresses depending on the affected device. The wheelchair is the “off-powered” part and is dragged by the bicycle. Due to that dragging, some undesirable momentums and torques can appear on the attachment.

Also, these technical aspects are not the unique features to consider. This design is thought to be used for standard bicyclist and wheelchair users so it is a requirement for it to be simple and comfortable to attach and remove.

Taking everything into account, it has to be easy to assembly and also be adaptable for the major number of frames and wheelchairs as possible.

8.2. ATTACHMENT DESIGN

First of all, in order for the bicyclist to have a comfortable access to the pedals, the wheelchair has to be located, at least, 25 [cm] from the bicycle frame. The connection mechanism has to be able to clearly establish this distance as it is shown on the figure 8.1.

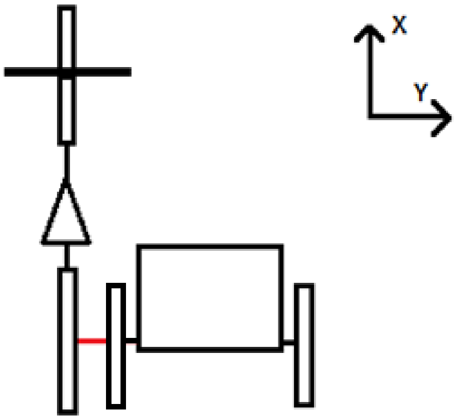


Figure 8.1. Location of the wheelchair and the bicycle from above.

Another consideration regards how many connection points make the optimum attachment, and directly related to that, they have to be common for most bicycles or wheelchairs in order to make easier the attachment mechanism search. For sure it will have and up-location and low-locations ones but it is considered to add a third one to get a more uniform forces' distribution along the frame.

Secondly, it is necessary to figure out if the whole wheelchair will be optimal for the sidecar behavior, since it has two caster on the front and two rear wheels on the back, a 4-wheeled vehicle. It is mandatory to consider how many contact points with the ground the final device will have, which can affect in the weight distribution effects and also in the steering of the final assembly.

These caster wheels influence considerably the movement of the wheelchair. Manual standard wheelchairs steers due to rear-wheel steering via propulsion torques, it is the rider propels the hand rims periodically. However, a correct tracking could be totally affected by the caster wheels. There is a sketch that can be seen in figure 8.2.

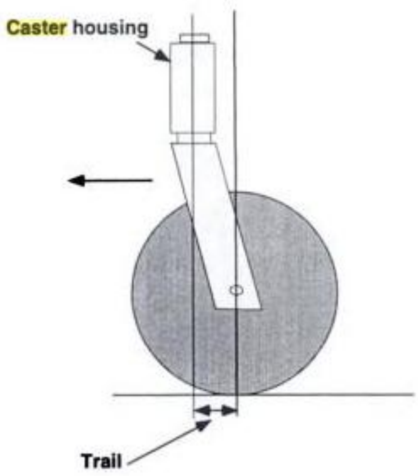


Figure 8.2. Caster wheels on a wheelchair with its trail.

Not only that, these wheels are characterized by a rapid side-to-side swiveling motion and when reaching higher velocities, depending on the caster wheel diameters, they can start rubbing and do not behave as expected.

Due to that, to prevent from possible setbacks provoked by these caster wheels and in order to assured the correct steering of the sidecar assembly; they will not be in contact with the ground. These caster wheels are not complicated to be installed and removed. Nevertheless, for an easier attachment for the user instead of removing them they will be placed on a certain distance to the ground. This fact is reached by a wheelchair backwards inclination. The connection must tilt the wheelchair and its user's weight will rely on the rear wheels.

Regarding the rear wheels, there are two decisive factors about what to do with the rear wheels. If it results in a 3-wheeled assembly is easier to steer. Nevertheless, in order to mount the assembly, the person on the wheelchair would have to rest somewhere and after the attachment it could get the chair again. On the other side, it is easier to attach if the left rear wheel is removed. Nevertheless, this decision also depends on the quick release characteristics.

Almost every wheelchair that can be found on the market counts with quick release system nowadays. This system makes really easy the wheel removal and installation, it is just necessary to press it and the wheel is practically already removed. As it can be seen on figure 8.3., the quick release remains inside the rear wheel axle and there is no space for any type of connection in a first view.

Figure 8.3. Mounted quick release on a rear wheel.

As it can be seen, the attachment is more difficult to make than expected. It is chosen to build a three-bars-connection between the two devices, which is the only way to make it consistent enough and also available for different bicycle frames and wheelchairs.

8.2.1. ATTACHMENT POINTS' LOCATIONS

In the chapter below, it has been explained the first aspects that has to be taken into account when designing a device like this. In order to start with the study, is mandatory to start thinking how the connection will be made. Consequently, is should be started from how this two different devices can be joined; it is the attachment points' locations. They have to be standardized points common to different devices, such as tubes or distances, to install the three bars.

Regarding the bicycle, the standardized points are located on the handle bar connection tube, or head tube, and the seat post tubes, which are suitable locations that only involves a concrete range of diameters. The third point, that has to be located in a lower height, is located on the bicycle rear wheel's axle; in where it is accessible to add a thin piece between the nut and the bicycle frame. They are showed on a sketch on the figure 8.4. located below.

Figure 8.4. Attachment point locations on a urban bicycle.

On the wheelchair, the attachment points are chosen similarly. The first attachment point is taken as reference one; it means that is attachment in which the bar positions one device respect the other one. It is known that wheelchairs nowadays counts with a quick release system in both rear wheels that makes really easy to install and remove them. So, the idea is to take advantage of this mechanism.

First of all, it has to be decided if the left rear wheel is removed or not. As it was mentioned before, due to the quick release characteristics, remember that it remains inside the wheel's hub when is perfectly attached, this rear wheel should be removed. Considering this case, it is has to be checked out in order to know if the axle would be able to stand the moments caused by the weight, acceleration, etc. since the wheelchair is designed to distribute the weight between two points in contact with the ground instead of only one.

From MBL company it is known that the quick release material can be hardened to a tensile strength,σ_y, of 1400 [N/mm^2]. The standardized diameter is 12 [mm] in Europe and 12.7 [mm] in the US, with an inner hole of 5 [mm]. If the European value is assumed as reference, is it possible to calculate the maximum bending moment that is able to stand. Just with the equation (8.1), [33]:

$$\sigma_{adm} = \frac{M_{b,max}\cdot c}{I} = \frac{M_{b,max}\cdot(\frac{d_e}{2})}{\pi\cdot\frac{(d_e^4 - d_i^4)}{64}} \qquad (8.1)$$

In where:

- σ_{adm}. Admissible tensile strength, taking into account the safety factor [N/m^2].
- $M_{b,max}$. Maximum bending moment, [N·m].
- c. Distance from the neutral axis to the outer surface where the maximum stress occurs, [m].
- I. Moment of inertia of an outer ring crossed section, [m^4].

So according to that the maximum bending moment admissible for a 12mm-diameter- quick release, taking into account a 5 [mm] diameter inner hole, with a safety factor of 1.5 is following (8.1):

$$M_{b,max} = \frac{\frac{1.4\cdot 10^9 [{}^N\!/_{m^2}]}{1.5}\cdot\frac{\pi(0{,}012[m]^4 - 0{,}005[m]^4)}{64}}{\frac{0.012[m]}{2}} = 154\ [N\cdot m]$$

This value will be taken as reference in a further resistant study to examine the attachment subjected to stress behavior.

The second attachment point, it is chosen to be at the same height of the seat tube connection on the bicycle. It makes the bar to be parallel to the ground and easier to examine and work with it.

Finally, the third one, distribute also the weight through the front part of the bicycle. In the wheelchair, the analogue point is located on the front part, just below the seat and will be in charge of standing the moment caused by tilting the wheelchair slightly backwards. These points are also showed on a sketch on figure 8.5.

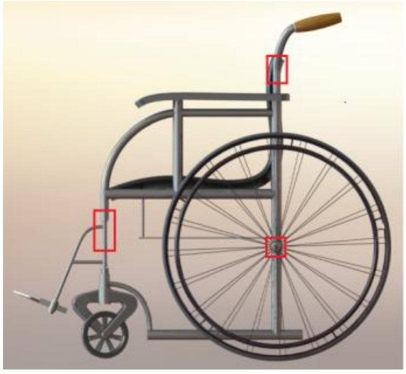


Figure 8.5. Attachment locations on the wheelchair.

8.2.2. ATTACHMENT COMPONENTS AND DESIGN

The attachment is thought to be a mechanism which involves three bars, clamps and some kind of a join piece related with the quick release system. These items and attachment mechanism are explained in the following paragraphs, focused in one connection each time.

The first attachment is made between the rear axle connection points from both devices. Just call it Bar 1, from now on.

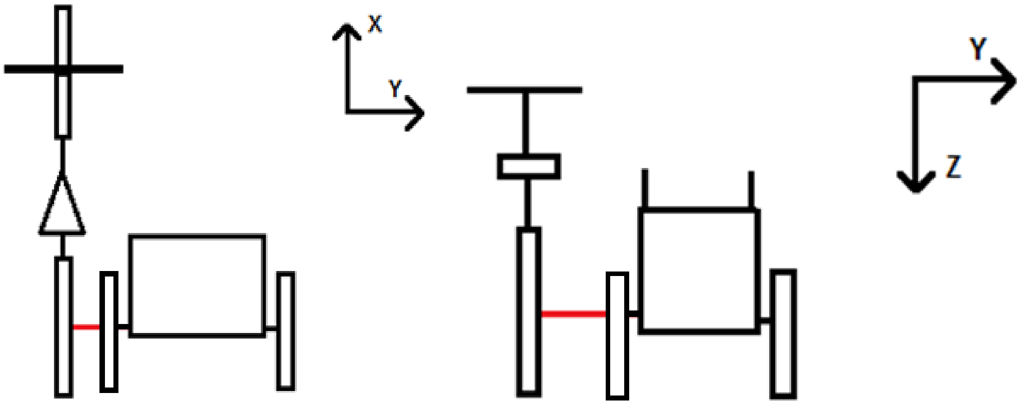


Figure 8.6. Bar one connection from above and from the back, respectively.

It was said above that this connection is on charge of positioning the wheelchair respect to the bicycle, around 250 [mm] from one edge to the other. The location can be seen on the sketches from figure 8.6.

This idea has to develop some issues before it is ready for being carried out. The most important ones can be resumed as:

- Whether the left rear wheel is removed or not.
- If it is removed, check if the quick release axle stands the stresses and moments caused in that point due to the removal.
- Deal with the different height of the axles. (Most common wheelchair rear wheels are 24[”] and in bicycles the most common ones reach 26[”]).

As first, it is consider the idea of removing the left rear wheel due to the quick release mechanism characteristics in most of wheelchairs; it is explained in chapter 8.2. and it remains inside the hub when attached.

This brings an important issue to us. The bar will be then joined with the quick release axle, considered as cantilever in that edge. As it was mentioned before it is calculated the maximum bending moment allowed by the axle through equation (8.1). Now that one of the contact points with the ground it is removed, the different users' weights will rely on the quick release axle and the right rear wheel. Since the quick release is not used to hold so much weight and bending moment, it is deeply examined below.

For a first approximation, it is taken into account just a static situation of both users simply mounting on the bicycle and wheelchair and their own weights. The free body diagram of this situation is showed on the figure 8.7.
It is examined the wheelchair because it will constitute it will be the heaviest member of the final assembly in most cases.

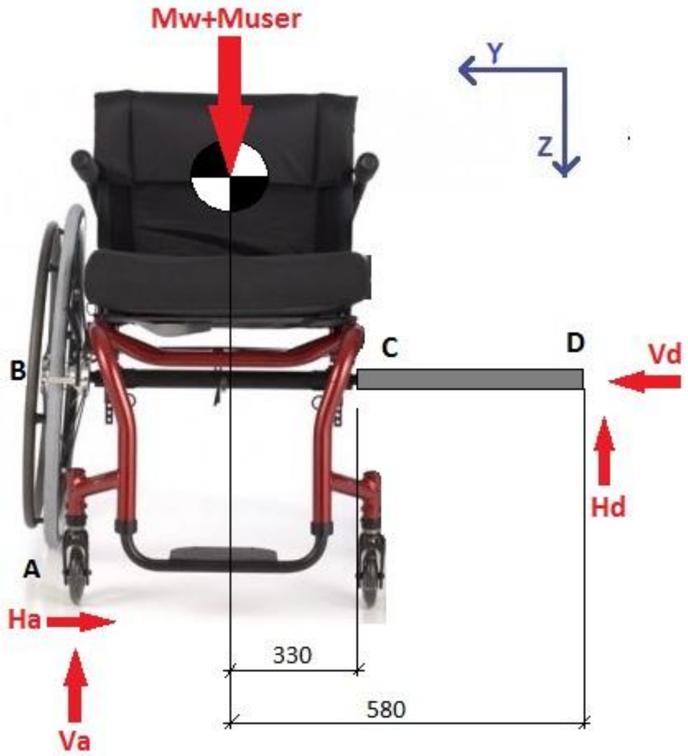


Figure 8.7. Free body diagram of a static simulation on the wheelchair with the first bar attached to the quick release.

Due to only vertical forces are taken into account, it is easily possible to assume that:

$$H_A \approx H_D \approx 0$$

Now, it is necessary to calculate the vertical forces responses in order to now the bending moment that appears on point B. As it can be easily noticed, the maximum bending moment will be caused by action on the forces on the edge of the bar, point A, so in here is calculated the shear response on this point.

$$V_D = \frac{\left((68[kg]+15[kg])\cdot 1{,}5\right)\cdot 9{,}81\left[\frac{N}{kg}\right]\cdot 0{,}33[m]}{0{,}580[m]+0{,}33[m]} = 442{,}9[N] \qquad (8.2)$$

This shear force calculated on the point D, which is the external edge of the connection bar, will provoke a bending moment on the quick release axle (located in point C). As moment in a certain point is calculated by multiplying the force by the distance from that to the force application force (250 [mm] of connection bar), it is reach:

$$M_C = F \cdot d = 442{,}9 \cdot 0{,}250 = 110{,}725[N \cdot m] \qquad (8.3)$$

The maximum bending moment allowed in the axle has been calculated on equation (8.1) and it reached 154 [N·m]. This result turns this assumption into a non adequate behavior for such a device. It has just been considered just a static analysis of forces and bending moment and it is almost reached the maximum allowable one for a quick release axle. If it is also considered some acceleration that can increase the forces on the system, then the breaking down probability increases considerably.

Referring to that, there are different possibilities to resolve the problem. If the rear wheel is removed, the bending moment on the axle has to be reduced. Either there is added another bar that could distribute the load or it is looked for another stronger material that could stand the load.

Regarding these considerations, it is come to the conclusion that the optimal option is not to overload that conflictive point. When removing the rear wheel the quick release connection point is subjected to undesirable efforts and could damage the whole wheelchair structure. Because of that, it is considered that the rear wheel must remains in the final assembly. Thanks to that, no point in the wheelchair is subjected to extreme load and the behavior is expected to be adequate even in hypothetic accidental situation, for example a huge bump in the road.

If the rear wheel is kept on the design, the wheelchair user’s weight is distributed as it used to be, equally between the two rear wheels. The excessive bending moment reached on the quick release axle is avoided.

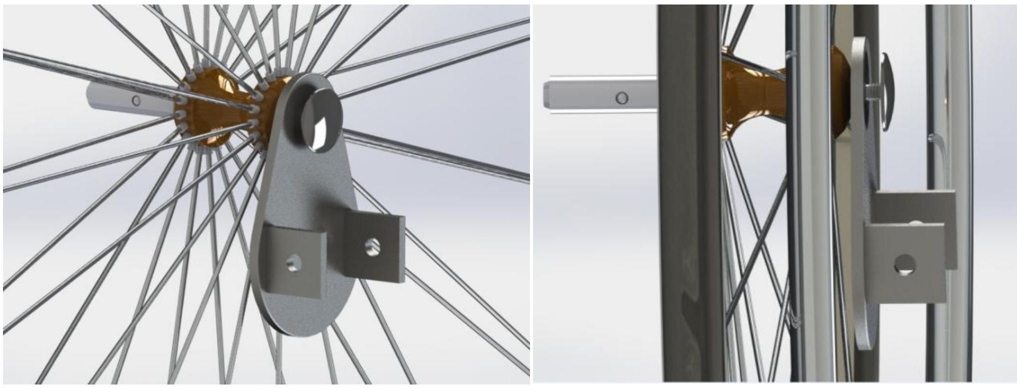
Nevertheless, this determination also brings some problems that have to be analyzed:

- The quick release remains inside the rear wheel hub in most cases. So it is more complicate to add something in that location.
- In a large number of attachments, the rear wheel axle on the bicycle and the one on the wheelchair will have different heights from the ground.

Considering first the issue about the space, it is necessary to check the possibility of changing the quick release to get some space available for make the connection. As it can be seen in more detailed in figure 8.8, the final part of the quick release finishes in a flat item that commonly ends aligned with the rear wheel hub. Worthy to mark that is the item that is pushed to remove and fix the axle.

Figure 8.8. Quick release briefly extracted from its bushing.

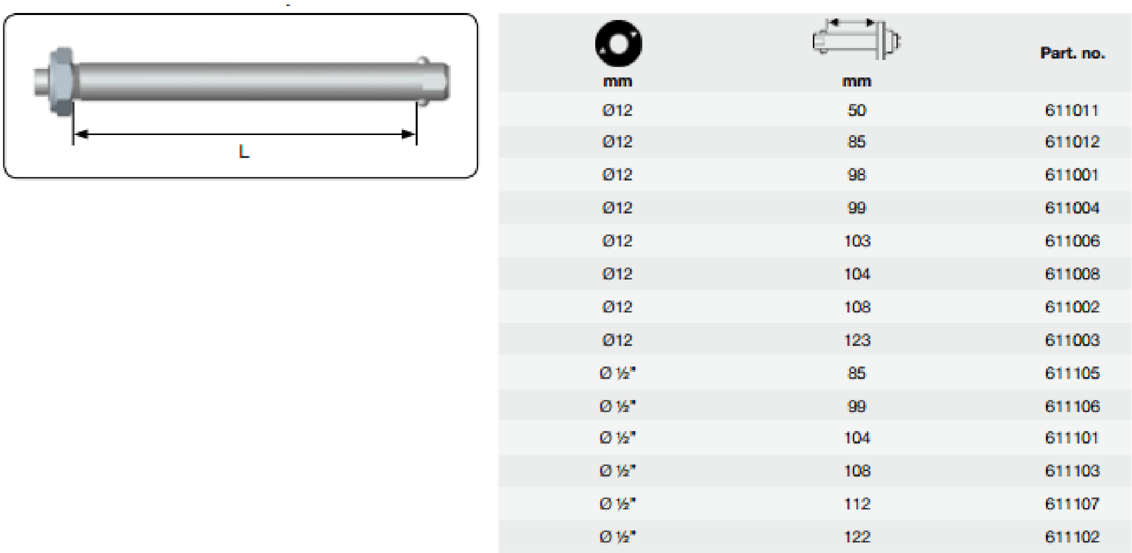
The bar has to be attached to it somehow and the idea is to attach a piece to the wheelchair wheel by the axle through a specific connection piece. It can be seen on figures 8.9. and 8.10.



Figures 8.9. and 8.10. Connection piece on the rear wheel QR-axle.

In order to reach that, the quick release axle that is used in the wheelchair that is being attached is not viable for the connection. The bushing distance is fixed in somehow that the axle is fixed when it is completely introduced in both bushing and hub.

Therefore, a larger quick release is required. According to MBL catalogue of quick release axles, the range of lengths available for 12[mm]-diameter ones goes from 50 to 123 [mm] regarding the distance showed in figure 8.11.



mm	mm	Part. no.
Ø12	50	611011
Ø12	85	611012
Ø12	98	611001
Ø12	99	611004
Ø12	103	611006
Ø12	104	611008
Ø12	108	611002
Ø12	123	611003
Ø ½"	85	611105
Ø ½"	99	611106
Ø ½"	104	611101
Ø ½"	108	611103
Ø ½"	112	611107
Ø ½"	122	611102

Figure 8.11. MBL quick release length catalogue, which is taken as reference.

Taking that fact into account, it is able to add to the design a larger axle than the one that is currently used in the wheelchair. The attachment method then it is quite simple: you just remove the “old” quick release axle from the wheelchair and install the “new” one with the attachment piece.

At this moment, it is the problem of different heights between bicycle and wheelchair hubs. Normal bicycles has wheel with diameters of 26 or 28[“] and the wheelchairs, in contrast, uses from 20 to 24[“] diameter rear wheels. In here, it is consider that the best option is to keep the bar parallel to the ground in order to make sure that the minimum distance between devices is 250 [mm].

The intention is to solve this problem just working on the machined attachment piece. Instead of add only one level in where the bar can be adjusted, it will be machined as it is possible to make different connections according the different heights.

The connection part between the rear wheel of the bicycle and the left wheelchair's wheel has been designed to keep the bar in a completely horizontal position in order to ease the mounting of the parts and distribute in a better way the forces on the same. You can see the design of the part in the figure 8.12.

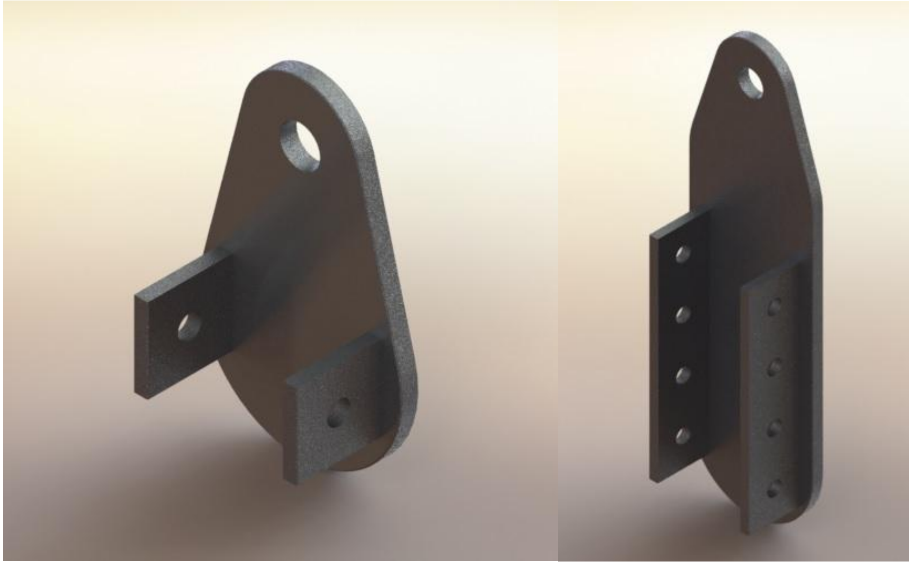


Figure 8.12. Connection piece with different heights.

Being the smallest the part which is connected to the wheelchair and the largest to the bicycle. The dimensions and the wholes have been designed to be able to fit with the most standard ranges of wheels sizes which are from 24''- 28'' for the wheels of the bicycles and from 20''- 22'' for the wheels of the wheelchairs. The bar and this piece are simply connected by a screw-nut connection.

For a more detailed forces and bending moment's knowledge, a resistant study is added to Appendix 5. In order to save material, this is a hollow bar and it is calculated that the minimum diameter that can handle the moments and forces applied are 26 [mm] as external one and 13 [mm] as the inner one.

The second attachment, or bar 2, it is easier to explain. It consists on a bar that goes from the seat post tube to the higher tube on the wheelchair (the one that joins the handle with the chair's back).

In order to get an approximate range of lengths that it has to fulfill to be adaptable for different bicycle sizes, there is a deeper dimensioning study on Appendix 4. It is calculated that this bar has to involve lengths from 350 to 400 [mm].

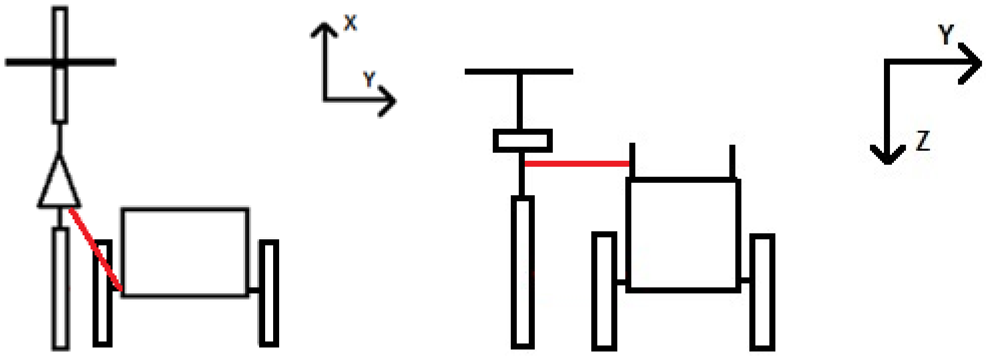


Figure 8.13. Sketches for bar 2 from above and from the back, respectively.

The functioning is easy. It is a telescopic bar which is made already manufactured by the company Parker steel manufacturer, which can provide manufactured telescopic bars as it required for the user. They are also made in aluminum so the final weight of the assembly still remains considerable.

After that, in order to adapt it to the frame, on both ends are attached two clamps. These clamps have a similar behavior as the ones that are used on truck's bicycle racks. They are made in two different parts, which perfectly allows enclosing every frame's tube and is also counts with a threaded lock knob to adjust the wanted diameter. The functioning is really easy; you simply install the frame inside the clamp and close it with the locker just turning it. Moreover, the inner part of the clamp (the one that is in contact with the frame tubes) is covered with some kevlar or organic mixed with aramid, graphite or metal fiber layer. These materials are characterized by their high friction factor, which will assure the correct situation of the clamps and avoid any kind of undesirable displacement or turning.

The idea is similar that the ones used by the company THULE ® and they are showed on the figure 8.15., just located below.

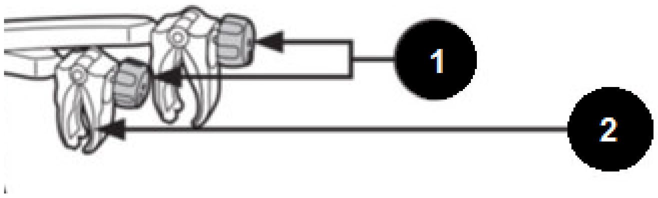
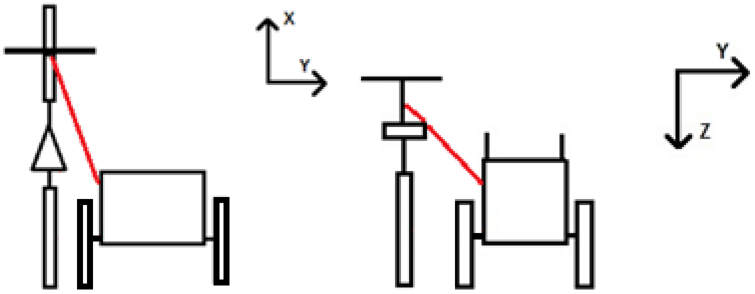


Figure 8.15. Clamps structure (2) with the lock knobs (1).

To make them strong enough to stand the stresses and bending moments that can appear both the clamps and the bars will made in aluminum 6061 T6. It involves the basic metals properties and also gets a really good corrosion resistance due to the thin aluminum oxide layer that naturally involves the entire piece. The aluminum has also a really great advantage: it has a relatively low density. Taking into account that the wheelchair itself and it users can be considerably heavy, it is recommendable to use light materials. More characteristics of this characteristic aluminum are showed on the appendix 6, as well of drawings of the bars in the appendix 7.

To get an approximate idea of how the dimensions that it must have, they are calculated the stress and moments on the bar and the minimum diameter that will stand them. So for the calculated diameters of 25 and 21[mm] on appendix 5, the maximum load that the bar is able to hold is 10600 [N] which means that is much larger than the applied on the bar. So according to that, it can be ordered a telescopic bar made of an inner tube of 25 - 21[mm] and an outer one of 30 – 26 [mm].

Finally, the third bar will be attached to the bicycle's head tube and the wheel structure just below the seat. It can be showed on the sketched below, figures 8.16 and 8.17. Another time, according to the dimensioning study on appendix 4, the range of lengths it must fulfill goes from 600 to 650 [mm].



Figures 8.16. and 8.17. Bar 3 connection from above and from the back, respectively.

As well as the bar 2, it is an aluminum-made telescopic bar with two clamps on both ends. The main characteristic of this bar is related to its duty on the assembly. This bar is on charge of standing all the moment caused by the wheelchair tilting and, because of that, it has to be strong enough to stand it. A deeper study is explained on appendix 5 and the final results of diameters are 44 and 18 [mm], outer and inner diameter respectively. According to the data provided by manufactured telescopic bars, Parker Steel, it is available a telescopic tube which involves an inner tube of 75 – 71 [mm] and an outer one of 80 – 76 [mm] as the most viable one.

8.2.3. ADDITIONAL FORCES ON THE SYSTEM

This part of the report considers other forces that will appear while using the device. These forces have been studied to reach a deeper knowledge about the general behavior of the assembly. Since the forces simulations used to dimension the bars are considered to subject the attachment to larger forces, these named ones will be perfectly stood in normal behavior.

Nevertheless, it is always useful to get to know how the sidecar will behave in different situations.

Rolling resistance

If a cylinder, radius R, rolls along a stationary base such that when it rolls through and angle ψ the axis of the cylinder is displaced relative to the base by an amount equal to $R\cdot\psi$, the pure rolling is said to exist. However, there is not a single point of contact but rather a distribution of the contact pressure along a slight ridge that is developed at a location towards the direction of travel. A driving force, F, must be applied to maintain and start the motion. The pressure distribution mentioned above can be represented by a resultant, normal force N, acting at a point of offset at a distance x perpendicularly through the center of the cylinder. With that it is possible to calculate the require force to start the motion and maintain it: the rolling friction appears when a body tries to roll over another one's surface.

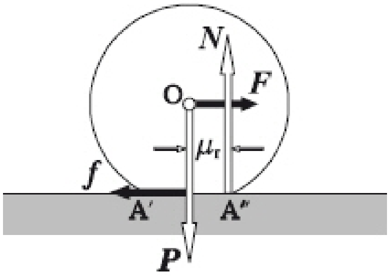
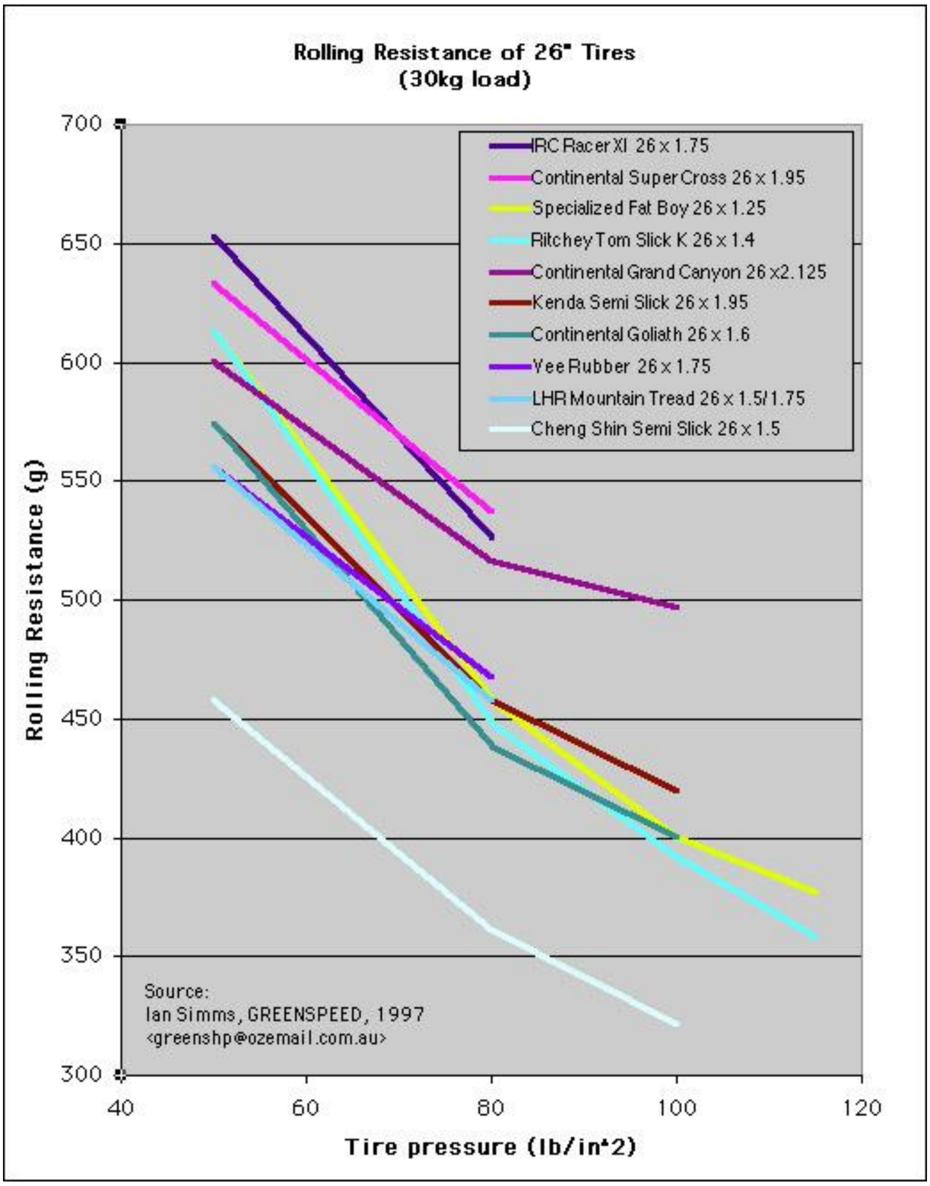


Figure 8.18. Forces that appear on rolling resistance.

A rolling resistance test has been carried out for different types of bicycle tires and the results are showed on the graph showed in figure 8.19.



Source:
Ian Simms, GREENSPEED, 1997
<greenshp@ozemail.com.au>

Figure 8.19. Rolling resistance for different kinds of tires.

Concretely, it has been tested on different tires for a load of 30 kg. Taking one as reference as, for instance, Continental Goliat with 26” wheel diameter as mayor number of bicycles nowadays, it is possible to calculate the rolling resistance in this case.

Firstly, it is known that normal tires has a pressure around 3.5 bar, or what it is the same, 50 pounds per square inch (as it is measured the plot).

For a 30 kilograms load and 50 pounds per square inch it is reaches a rolling resistance of 560 grams, equal to 5,49 [N]. Assuming that there is a direct relationship between the load and the rolling resistance, for the total device weight (supposed to be 244,5 kilograms with the weight safety factor) the rolling resistance increases up to 44,74 [N].

As it is easily appreciable, it is not a huge force that has to be over pass. Because of that, it could be seen that comparing to different loads and stresses from which the device will be subjected, these ones have not such a large influence.

Centrifugal forces

Centrifugal forces acts outwardly from the centre of the curve. Moreover, it can directly affect the whole device's roll. Normally, when you turn with your usual bicycle, you lean unconsciously the bicycle to balance the forces that appear when turning. However, it is impossible to lean with this bicycle-wheelchair coupling because it works as a rigid vehicle.

When turning the assembly right or left, a centrifugal force is generated. According to basic physics a force is equal to mass multiply its acceleration but, in case of a circular motion as this bicycle-wheelchair turning, the centrifugal force it is defined as:

$$Fcen = m \cdot \frac{v^2}{r} \tag{8.4}$$

In where:

- m: Whole device mass (Bicycle + Wheelchair + Users), [kg].
- v: Velocity at the time of turning, [m/s].
- r: Curve radius [m].

This force tries to force the device outwards of the curve but it also has another undesirable consequence over the sidecar assembly.

Weight force,W_T, acts vertically downwards through the center of gravity and the centrifugal force, F_{cen}, acts horizontally through the same point. To continue with this explanation it is mandatory to figure out where the centre of gravity is exactly located.

These calculations are showed on Appendix 5 (resistant study) and the results are:

- $x_{CM} = 423[mm]$
- $y_{CM} = 295[mm]$
- $z_{CM} = 750[mm]$

It is simple to notice that weight force, acts at certain distance (look plane YZ) from the point taken as reference. Concretely it acts at a 295 [mm] distance on the Y-axis. The centrifugal force, however, acts horizontally at a vertical distance (of 750 [mm]) on the Z-axis.

Both of them subject a moment and, therefore, are two moments acting:

- The weight moment that holds the sidecar onto its wheels.
- The centrifugal moment that tries to lift the sidecar from the ground.

To make a turn safely and with no sensation of losing control, for beginners maybe see the wheelchair lifting could make them feel insecure. It is necessary to keep the weight moment over the centrifugal one, or what is the same, follow the inequation (8.5):

$$w_{Total} \cdot d_{Y-CG} \geq F_{cent} \cdot h_{CG} \qquad (8.5)$$

If the weight moment is larger than the one caused by the centrifugal force, the sidecar will not lift. According to this, it is possible to calculate the maximum speed recommended for a certain curve radius.

First of all, it can be calculated the weight momentum:

$$M_{weight} = W \cdot d_{Y-CG} = (12 + 15 + 68 + 68) \cdot 1{,}5 \cdot 9{,}81 \cdot 0{,}295 = 707{,}57[N \cdot m] \qquad (8.6)$$

In where:

- $W = m \cdot g$. And 1.5 is the weight security factor.

Now, for the sidecar to remain in the ground, the centrifugal moment has to reach a lower value. It is calculated by equation:

$$M_{cent} = m\frac{v^2}{r} \cdot h \qquad (8.7)$$

In where h is the center of mass' height.

For a curve radius interval from 2 to 15 [m], with 0,5 [m] steps, has been calculated the following maximum speeds in order not to lift the sidecar, according to inequation:

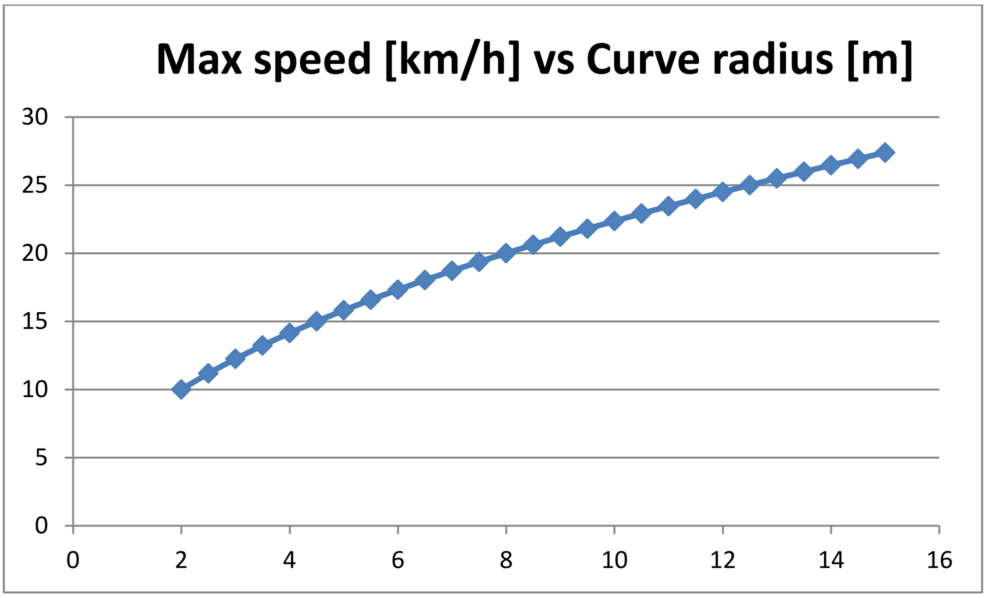


Figure 8.20. Max speed allowed vs curve radius in order not to lift the sidecar part, when turning right.

As reference, for a sharp turning as 2 [m] radius, the maximum reachable speed is 10 [km/h] and for a 15-[m]-radius one, it is possible to reach almost 28 [km/h]. Taking to account the fact that as maximum common speed for a bicycle reaches around 25 [km/h], it is easy to assume that this assembly will not reach as high speeds. If the bicyclist is careful enough, an inappropriate behavior will not appear when turning.

So, the maximum centrifugal force that can be reached in a curve is 943,43 [N], for this certain approximate case. If the bicyclist turns too fast to the right, this force will be over passed and the sidecar will lift.

Since the right turning has been explained, it is also correct to calculate same parameters when turning left.

In this case, the weight momentum changes because now the distance that has to be considered is the distance from the center of gravity to the outer part of the device in the curve. The sidecar acts as a stabilizer in left-hand turns and it is possible to reach higher velocities that can be calculated with the same method as the ones in right turning just changing the distance in the weight momentum to 615 [mm]. In this case, the moment is calculated as (8.6):

$$M_{wght} = (12 + 15 + 68 + 68) * 1{,}5 * 9{,}81 * 0{,}615 = 1475{,}11 [N \cdot m] \qquad (8.8)$$

The moment is greater than in right turning and, logically, the centrifugal force has to be higher to over pass the weight momentum. Concretely, the reachable velocities are shown in picture 8.21.:

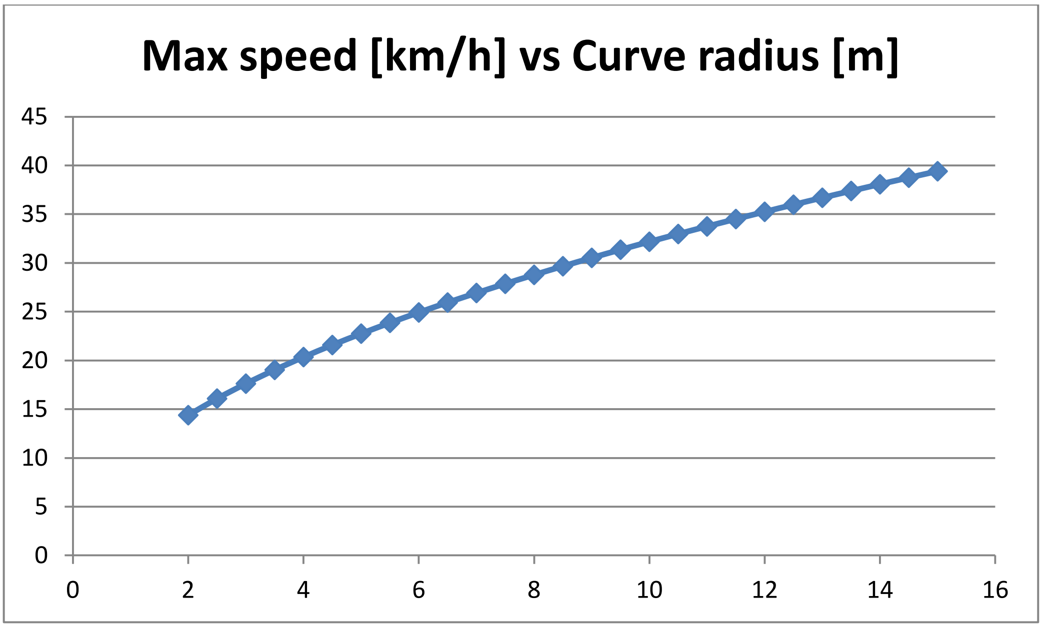


Figure 8.21. Max speed allowed vs curve radius in order not to lift the sidecar part, when turning left.

And the centrifugal force reaches, according to equation (8.4):

$$Fcen = m \cdot \frac{v^2}{r} = 1953{,}48[N]$$

Although the centrifugal force is larger than in turning case, the weight moment keeps the contact between sidecar and ground for a correct behavior. According to that, the velocities reaches here goes from 14,4 [km/h] until 40 [km/h] for really open curves.

*Formulas based on [35] KENDALL, H. *Sidecar 2003*.

8.3. SAFETY FACILITIES

8.3.1. BREAKING SYSTEM

According to Danish Bicycle Legislation, 2012, every kind of bicycle has to count with two differentiated brakes, one for each wheel. They are shown in figure 8.22.

The braking system remains from the bicycle. The device counts with two brakes which under the bicycle user's control: one for the front wheel and one for the rear wheel. Moreover, according to the Danish Bicycle Legislation approved on January, 2012, for more information check Appendix 1, it also counts with a mechanical brake in order to make the assembly remain stopped when required.

Figure 8.22. Mechanical breaking system on the wheelchair.

8.3.2. PERSONAL SAFETY SYSTEM

In order to assure the passenger's safety, special seat belts must be attached to the device.

The optimum way to assure the user to the wheelchair structures can be reached by just a simple seatbelt. A large number on available wheelchair also counts with this safety system already installed, it depends on the mobility grade of the user in the major number of cases.

Figure 8.23. and 8.24. Front and back part of the safety system.

As it can be seen on figure 8.23. and 8.24., the system involves two different parts. The back part is firmly attached to the seatback part of the wheelchair, and remains there as long as required. Then, the front part is removable and it has to be attached only when required. The great advantage of this seat belt is that it can perfectly hold the user, no matter their grade of mobility or preferences.

This concretely seat belt system is provided by the English company Unwin safety systems. Moreover, it is simply removable with a press-to-release system, which is the same mechanism used in common cars and vehicles.

8.3.3. LIGHTS AND EXTRA WHEEL

According to the Danish Bicycle Legislation from January 2012 compels to this kind of devices to have a red light on the righter part of the sidecar, which means that with the attachment mechanism it will be included in the kid.

Not only that, and taking into account the possibility that some kind of accident could happen, it is considered the option to add some kind of attachment mechanism for a spare wheel.

It is easy; just install two hooks on the handle bars looking to the back. Those consist in two plastic pieces with a hole that are introduced around the handle and placed on the back. Then the wheel can be simply attached just hanging its radius.

9. BUDGET

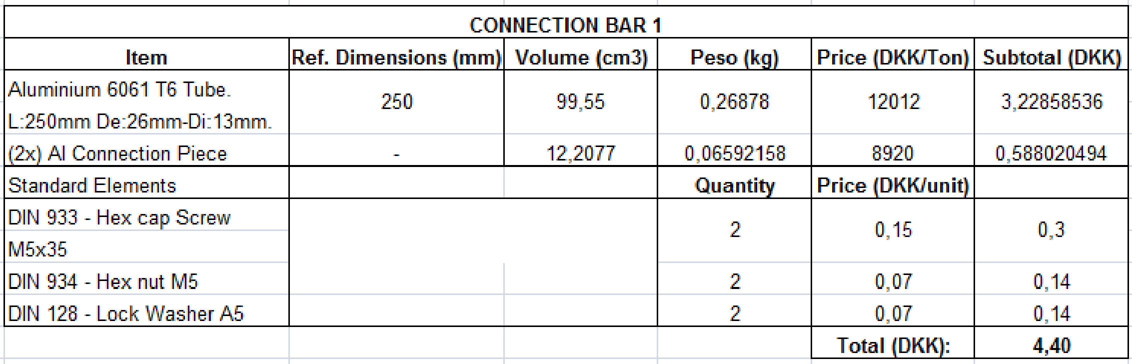
In this part of the study it is developed the estimated budget by unit of the design. IT has been taken into account different parameters in order to get the most real approximation:

- Raw materials.
- Workforce.
- Production costs.
- General costs.
- Amortization.

(Most parameters are related with Spanish taxes, regulations, etc.)

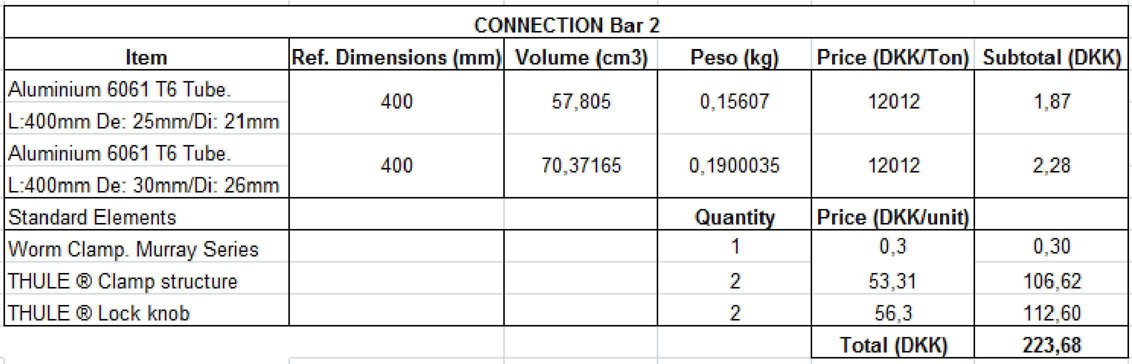
Raw materials:

In here is made a detailed relation explanation of all the materials required for the construction and assembly of the device, tables 9.1., 9.2. and 9.3. As it was not possible to contact with the provider company it is made an approximation if they were also made for the designer.



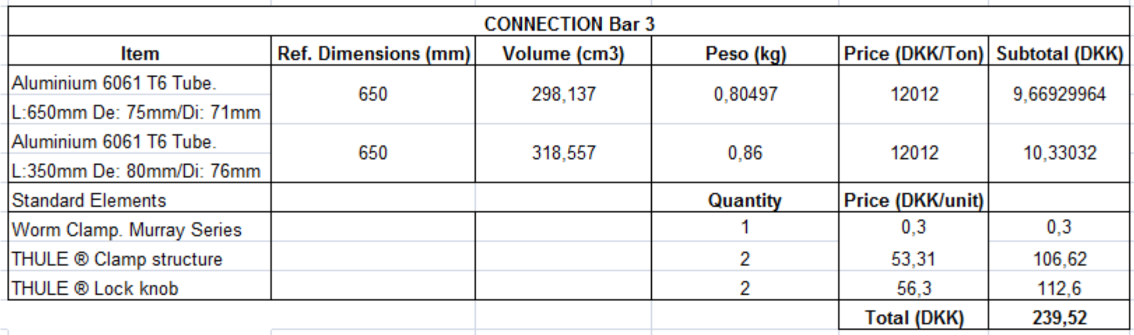
CONNECTION BAR 1					
Item	**Ref. Dimensions (mm)**	**Volume (cm3)**	**Peso (kg)**	**Price (DKK/Ton)**	**Subtotal (DKK)**
Aluminium 6061 T6 Tube. L:250mm De:26mm-Di:13mm.	250	99,55	0,26878	12012	3,22858536
(2x) Al Connection Piece	-	12,2077	0,06592158	8920	0,588020494
Standard Elements			**Quantity**	**Price (DKK/unit)**	
DIN 933 - Hex cap Screw M5x35			2	0,15	0,3
DIN 934 - Hex nut M5			2	0,07	0,14
DIN 128 - Lock Washer A5			2	0,07	0,14
				Total (DKK):	**4,40**

Table 9.1. Unitary cost for connection Bar 1.



CONNECTION Bar 2					
Item	**Ref. Dimensions (mm)**	**Volume (cm3)**	**Peso (kg)**	**Price (DKK/Ton)**	**Subtotal (DKK)**
Aluminium 6061 T6 Tube. L:400mm De: 25mm/Di: 21mm	400	57,805	0,15607	12012	1,87
Aluminium 6061 T6 Tube. L:400mm De: 30mm/Di: 26mm	400	70,37165	0,1900035	12012	2,28
Standard Elements			**Quantity**	**Price (DKK/unit)**	
Worm Clamp. Murray Series			1	0,3	0,30
THULE ® Clamp structure			2	53,31	106,62
THULE ® Lock knob			2	56,3	112,60
				Total (DKK)	**223,68**

Table 9.2. Unitary cost for connection Bar 2.



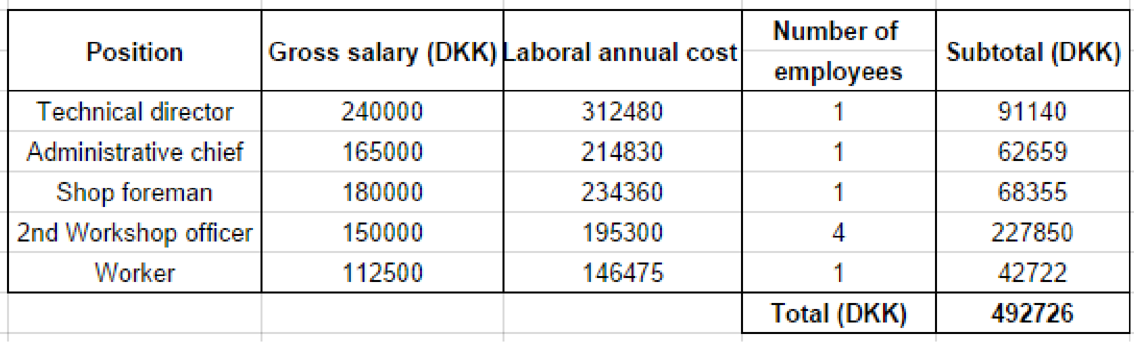
CONNECTION Bar 3					
Item	**Ref. Dimensions (mm)**	**Volume (cm3)**	**Peso (kg)**	**Price (DKK/Ton)**	**Subtotal (DKK)**
Aluminium 6061 T6 Tube. L:650mm De: 75mm/Di: 71mm	650	298,137	0,80497	12012	9,66929964
Aluminium 6061 T6 Tube. L:350mm De: 80mm/Di: 76mm	650	318,557	0,86	12012	10,33032
Standard Elements			**Quantity**	**Price (DKK/unit)**	
Worm Clamp. Murray Series			1	0,3	0,3
THULE ® Clamp structure			2	53,31	106,62
THULE ® Lock knob			2	56,3	112,6
				Total (DKK)	**239,52**

Table 9.3. Unitary cost for connection Bar 3.

Workforce:

In order to evaluate the costs caused by workforce, it has been considered an enterprise with contracted workers. In this case in where the designers are from Spain, the considerations have been made according Spanish salaries and Spanish social security,

1300 units are taken as a reference number of built pieces, it also is considered that in three months and a half all of them will be made. And the rest of the time will be used in other systems. In the table 9.4. can be seen the result.



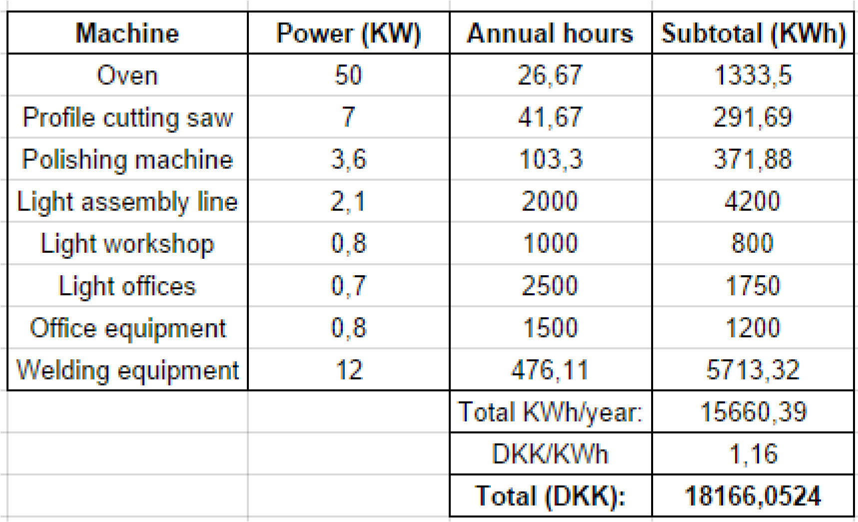
Position	Gross salary (DKK)	Laboral annual cost	Number of employees	Subtotal (DKK)
Technical director	240000	312480	1	91140
Administrative chief	165000	214830	1	62659
Shop foreman	180000	234360	1	68355
2nd Workshop officer	150000	195300	4	227850
Worker	112500	146475	1	42722
			Total (DKK)	**492726**

Table 9.4. Workforce approximation for budget.

Production costs:

Electricity:

All the machinery required will spend money while using it. It has been considered a maximum of 8 hours per day, 245 days per year functioning, the cost is estimated on table 9.5.

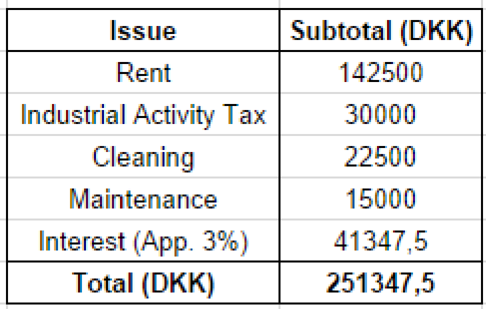


Machine	Power (KW)	Annual hours	Subtotal (KWh)
Oven	50	26,67	1333,5
Profile cutting saw	7	41,67	291,69
Polishing machine	3,6	103,3	371,88
Light assembly line	2,1	2000	4200
Light workshop	0,8	1000	800
Light offices	0,7	2500	1750
Office equipment	0,8	1500	1200
Welding equipment	12	476,11	5713,32
		Total KWh/year:	15660,39
		DKK/KWh	1,16
		Total (DKK):	**18166,0524**

Table 9.5. Estimated costs due to electricity.

Indirect costs:

External costs completely related with production are shown in table 9.6.:

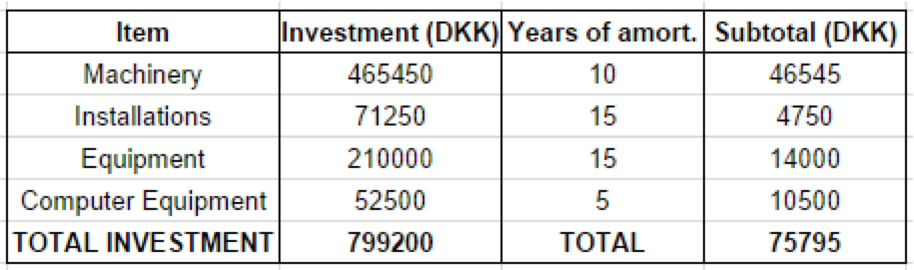


Issue	Subtotal (DKK)
Rent	142500
Industrial Activity Tax	30000
Cleaning	22500
Maintenance	15000
Interest (App. 3%)	41347,5
Total (DKK)	**251347,5**

Table 9.6. Costs due to diverse causes.

The interests are considered to be paid over the 80% of the initial investment.
Indirect costs per unit: 161,60 DKK.

Amortization:

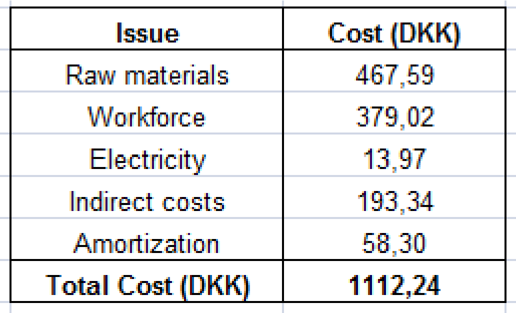


Item	Investment (DKK)	Years of amort.	Subtotal (DKK)
Machinery	465450	10	46545
Installations	71250	15	4750
Equipment	210000	15	14000
Computer Equipment	52500	5	10500
TOTAL INVESTMENT	**799200**	TOTAL	**75795**

Table 9.7. Amortization costs.

Cost per unit due to amortization: 58,5 DKK.

In order to get the unitary cost for everything, all the calculated prices have to be divided in the number of expected to be made units: 1300. With all that information, the final budget of the attachment method is shown in table 9.8. :



Issue	Cost (DKK)
Raw materials	467,59
Workforce	379,02
Electricity	13,97
Indirect costs	193,34
Amortization	58,30
Total Cost (DKK)	**1112,24**

Table 9.8. Final price.

10. FUTURE STUDIES

This study can be considered as a first step in the design of a coupling method between a bicycle and a wheelchair.

As it has been mentioned several times along the report, the huge amount and versatility of frames and wheelchair designs makes almost impossible the design for such an adjustable device in a short period of time. Nevertheless, it will be completely recommendable to keep working on the adaptability side of the design. It would turn the current design into a much more attractive one for the common customer.

11. CONCLUSION

Here it explained one possible coupling method between a common urban bicycle and non foldable wheelchair. There are plenty of different methods which can be used to attach these two devices. However, it gets more difficult if you take into account the huge variety of frames and structures available in the market.

Nevertheless, the one previously explained has tried to be the easiest as possible in order to get more attractive for common costumers. It just involves three bars telescopic bars which are attached to the bicycle frame and wheelchair through really easy to lock clamps. The fact that they are also easily fixed in a certain length makes the attachment even easier and comfortable.

Regarding the manufacturing side, the aluminum tubes are really easy to fabricate due to this kind of material natural properties. The little connection piece will required to be machine and the clamps can be ordered to THULE ®, in where they are as available as spare pieces.

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