Design of a new transformation device for a tip seat for multifunctional public transportation
Graduation project

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Preface

In the continuation of my literature research for my study Mechanical Engineering at Delft University of Technology, this report is the result of my final thesis. This project is performed for Tribus b.v. which is a company in Utrecht that converts conventional minibuses for multi-functional (public) transportation. The goal is to design a new tip seat that exceeds seats of competitors on price, weight, operation and functionality.

This report shows the new concept of this tip seat that is used as a passenger seat and can be transformed in a small package that creates the necessary space for the transportation of wheelchair occupants. The mechanisms needed for this transformation are elaborated in further detail.

I would like to give my thanks to my supervisors Riender Happee and Dick Plettenburg and my executives Herman Rigterink and Iddo Verweij for their discussion, remarks and support during the realization of this report.

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Eric van Vliet
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Abstract

Tribus b.v. is a company in Utrecht that converts minibuses for multifunctional public transportation. This means that with the same bus both ambulant people and wheelchair occupants can be transported. The multifunctionality lies in the combination of a flexible floor layout and (tip) seats. The floor system is based on separate aluminium profiles that are assembled to form any desired floor layout. Tribus’ tip seat (*FlexusPRO*) meets the highest quality and safety requirements. Because of its integrated three point safety belt, the seat can be positioned anywhere in the vehicle.

A common seat layout is the 4x4 tip seats, where four *FlexusPRO* seats are positioned on the right side of the vehicle and four on the left. By folding the seat pan to the backrest and subsequently rotating the seat package to the side, a wheelchair environment is created without removing or repositioning the seat. This transformation from passenger seat (mode 1) to wheelchair space (mode 2) is an easy and fast operation that enables the transporter to do a combined transportation of ambulant people and wheelchair occupants with the same vehicle.

Besides the benefits of Tribus’ *FlexusPRO*, the tip seat also has some main drawbacks with respect to the production costs, weight, the available wheelchair space after seat transformation and the hindered view outside for the wheelchair occupant as a result of the seat dimensions in mode 2.

The goal is to overcome these drawbacks, in order for Tribus to be able to launch a new tip seat that exceeds seats of competitors on price, weight, operation and functionality. The goal of this graduation project focuses on the improvements of the seat position in mode 2. This means an improvement of the transformation device, where the overall goal is to reduce the production costs and weight by at least 30% and increase the view outside for the wheelchair occupant by at least 20% in combination with an increased lateral wheelchair space of at least 10%.

However, in order to obtain a good design, a complete concept of the new tip seat needs to be proposed, where every aspect of the seat is able to fulfil the design requirements. A morphological approach resulted in three tip seat concepts that are rated with respect to usage and manufacturing aspects. The final concept led to a tip seat with a rotation device and a tilting backrest, that increases the lateral wheelchair space in mode 2. The improvement of the lateral wheelchair space is however dependent on the entire seat design, where the base frame of the seat will be leading. Because the base frame of the seat is not part of this project, a specific percentage of the improvement is not yet known, but an improvement of at least 10% can be realized. The separate headrest of the seat is moved down during the transformation to mode 2, which improves the view outside for the wheelchair passenger. The entire seat design is also not part of this project, but research on commercial vehicles showed that a vertical adjustment
of the headrest of 210 mm is possible, which would improve the view outside by approximately 33%. The new seat concept is used as a guideline for the design of the two mechanisms that are needed for the transformation from mode 1 to mode 2.

The tilting motion of the backrest resulted in a mechanism that provides a simultaneous movement of both backrest and seat pan. The benefit is that the additional (tilting) functionality of the seat had no effect on the amount of operations needed for the transformation. The mechanism is based on the over-centre principle of a toggle clamp. The system uses four pivot points that connects the backrest to both seat pan and seat frame. This innovative solution resulted in the fact that no additional locking devices were necessary to prevent the angular movement of the backrest in mode 1. The loads on the three point belt in the backrest, as a result of a frontal impact, are transferred into the mechanism which is only locked by the geometry of the backrest and seat pan. This mechanism prevents additional costs and weight as a result of the additional tilting functionality.

Finally a new rotation device is designed. The use of a morphological approach resulted in four concepts. The best concept is elaborated, resulting in a new steel swivel of 3 kg, which is a weight reduction of 38%. Because of the minimal amount of components, no welding operations and an easy and fast assembly, the cost price of the swivel is reduced by 47%.

Both tilting mechanism and swivel have been prototyped and they underlined the benefits that are mentioned in this report. The swivel has even been tested by a physical pull test and passed this test successfully. The goal of reducing the production costs and weight by at least 30% has been exceeded on both aspects. The view outside for the wheelchair occupant could be improved by 33%, which also exceeds the required 20%. The required improvement of the lateral wheelchair space by 10% can still be realized and will exceed this 10% especially around the arms of the wheelchair occupant. The project has been a success and Tribus decided to continue the development of both mechanisms for series production.
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Nomenclature

This page shows a list of definitions of the terms used in this report.

Airline track A specific rail with a continuous pattern of holes that is used for fixing seats and wheelchairs inside a minibus (see Figure 1.1).

Fixed seat A seat used in minibuses where the seat is fixed to the base frame and cannot be swiveled.

*FlexusPLUS* Tribus’ current fixed seat.

*FlexusPRO* Tribus’ current tip seat.

*M1* A vehicle is categorized into different vehicle categories. Vehicle category M stands for vehicles with at least four wheels that are designed and build for transportation of persons. The M1 is a classification within category M and stands for vehicles with a maximum of eight seats (driver seat excluded) that are designed and build for transportation of persons.

Mode 1 The tip seat has two functional modes that are used in a minibus. The condition of the tip seat where the seat is in a seating position is addressed as the first functional mode.

Mode 2 The tip seat has two functional modes that are used in a minibus. The condition of the tip seat where the seat is transformed in such a way that wheelchair space is created, without removing the seat from the bus, is addressed as the second functional mode.

*RDW* Abreviation for *Rijksdienst voor het Wegverkeer* which is an institution that monitors the registration of motorized vehicles and driving licenses in the Netherlands.

Swivel A transformation device that allows the seat to rotate relative to the base frame of the seat.

Tip seat A seat used in minibuses where a part of the seat can be folded to the other part (tipped) and consequently the complete package can be positioned in such a way that the additional space created can be used for a wheelchair occupant.
Chapter 1

Introduction

In the early days, combined transportation of ambulant people and wheelchair occupants was a time consuming business. Before the driver of the transportation vehicle was able to transport a wheelchair occupant, he first had to drive to the company to remove a couple of seats from the bus in order to create the necessary wheelchair space. One can imagine that several rides a day with ambulant passengers, wheelchair occupants or a combination of these two was a very cumbersome operation. In recent years, the tip seat was introduced which makes it possible to transform the seats in such a way that wheelchair space is created without removing the seat from the bus. This time saving functionality of the seat is a good solution for the transportation companies.

In this chapter Tribus’ current tip seat *FlexusPRO* is discussed which underlines the benefits of a tip seat (1.1). Furthermore the limitations of the seat are elaborated (1.2) which results in the problem definition of this graduation project (1.3).

1.1 FlexusPRO

Tribus B.V. is a company in Utrecht that converts conventional minibuses for multifunctional (public) transportation which meet the highest quality and safety requirements. The vehicles are equipped with a floor system based on aluminium profiles that can be assembled to form any desired floor layout. Some of these profiles have an airline track, which is a specific rail with a continuous pattern of holes that is used for fixing seats and wheelchairs inside the minibus. In Figure 1.1 these specific profiles are shown.

![Figure 1.1: Aluminium floor profiles with and without airline track](image)
There are two types of seats that are used by Tribus, dependent on the type of transportation the vehicle is used for. Tribus’ fixed seat FlexusPLUS can be positioned anywhere on the airline track and is mostly used by companies that mainly transports ambulant passengers. For the occasional wheelchair transportation, the seats are repositioned in the vehicle, to create the necessary, varying numbers of wheelchair space, or being removed from the bus. For the combined transportation of ambulant passengers and wheelchair occupants, the FlexusPRO tip seats are used, that can also be positioned anywhere on the airline track, but have the possibility to transform in such a way that it provides the additional space for the transportation of a wheelchair occupant as well. These tip seats will be the focus of this report.

The strength of the tip seat lies in the additional wheelchair space that is obtained within a couple of seconds, without removing the seat from the bus. This is not only a time saving functionality, but also a relief for the driver who previously had to remove multiple heavy seats (± 32 kg) from the bus in order to obtain this necessary wheelchair space. In Figure 1.2 the transformation of Tribus’ current tip seat FlexusPRO is shown. The transformation is performed by firstly moving the armrest and the seat cushion to the backrest. Secondly the red lever above the base frame of the seat is operated, which enables the rotation of the seat package. Rotation of the seat is possible until it automatically locks in its new position.

Tribus is able to offer the customer a high quality multifunctional minibus with the Flexus-PRO, which permits the driver to transport eight ambulant people, up to six wheelchair occupants or a combination of these passengers.
1.2 Limitations

Despite all the benefits of the tip seat, the FlexusPRO has also its limitations. In this section the limitations are enumerated and discussed in further detail per subsection.

1.2.1 Weight

A vehicle is categorized into different vehicle categories. Vehicle category M stands for vehicles with at least four wheels that are designed and build for transportation of persons. The M1 is a classification within category M and stands for vehicles with a maximum of eight seats (driver seat excluded) that are designed and build for transportation of persons [7]. The FlexusPLUS and FlexusPRO has been tested according to the M1 EU directives which are the most severe for this vehicle category. Because the M1 minibuses require seats with three point safety belts all FlexusPLUS and FlexusPRO seats have integrated three point belts. One of the EU directives is the 76/115/EEG which concerns the anchorage points for the safety belts, where the test procedures are prescribed regarding strength and geometry requirements. During an impact the seat not only has to withstand the loads that occur due to the weight of the seat, but because of this integrated safety belt also the loads due to the weight of the occupant. This means that seats with integrated three point belts have to withstand a horizontal load of 13,7 kN on the shoulder belt, together with 13,7 kN in addition to a load of 20 times the weight of the seat on the lap belt [3]. Because of these tremendous loads most structures for these type of seats become very heavy, which also applies for the FlexusPLUS and FlexusPRO that weigh up to 32 kg.

Restricted gross weight

Each vehicle that is converted by Tribus is inspected by the Rijksdienst voor het Wegverkeer (RDW) which is an institution that monitors the registration of motorized vehicles and driving licenses in the Netherlands. The M1 vehicles are restricted to a maximum gross weight of 3500 kg [7]. In equation (1.1) one can see that for a minibus with a capacity of six wheelchairs the maximum weight that can be used for conversion (conversion weight) is 600 kg. Equation (1.2) shows that reducing this weight with the gross weight of the aluminium floor and the weight of the seats, the maximum restricted gross weight for a M1 vehicle is nearly reached. It directly indicates the importance of reducing the weight of the seats, which is currently over 42% of the conversion weight, to obtain more freedom in additional work for the conversion of the vehicle.

\[
W_{\text{conversion}} = W_{\text{max}} - W_{\text{vehicle}} - 9 \cdot W_{\text{person}} - W_{\text{lift}} \\
= 3500 - 2100 - 9 \cdot 75 - 125 \\
= 600 \text{ kg}
\]

\[
W_{\text{rest}} = W_{\text{conversion}} - W_{\text{alufloor}} - 8 \cdot W_{\text{seat}} \\
= 600 - 300 - 8 \cdot 32 \\
= 44 \text{ kg}
\]
CHAPTER 1. INTRODUCTION

Where

\[
\begin{align*}
W_{\text{conversion}} &= \text{The maximum weight that can be used for conversion} \quad \text{[kg]} \\
W_{\text{max}} &= \text{The maximum restricted gross weight for a M1 vehicle} \quad \text{[kg]} \\
W_{\text{vehicle}} &= \text{The net weight of the vehicle with a capacity of six wheelchairs} \quad \text{[kg]} \\
W_{\text{person}} &= \text{The weight that is used by the RDW for 1 person} \quad \text{[kg]} \\
W_{\text{lift}} &= \text{The weight of the wheelchair lift} \quad \text{[kg]} \\
W_{\text{alufloor}} &= \text{The gross weight of the aluminium floor with wheelchair restraint systems} \quad \text{[kg]} \\
W_{\text{seat}} &= \text{The gross weight of the seat} \quad \text{[kg]}
\end{align*}
\]

Labour conditions

Another thing that has to be taken into consideration are the labour conditions. The National Institute of Occupational Safety and Health (NIOSH) concluded that in the most optimal situation one is allowed to lift a maximum weight of 23 kg to prevent any health damage [10]. This means that the FlexusPLUS’s and FlexusPRO’s current weight of 32 kg is too heavy to lift by one person without additional tools. In case of the FlexusPLUS seats, the weight reduction of the seat is not only beneficial for the health of Tribus’ employees but also for the driver who occasionally has to reposition or remove the seat as discussed in section 1.1.

Fuel and CO$_2$ reduction

Besides the benefits of weight reduction for Tribus, less weight is also beneficial for the customer with respect to fuel consumption. The increasing oil prices have its influence on transportation costs and in addition to the fuel efficiency of the current vehicle engines weight reduction is effective when it comes to fuel economy. Research shows that reducing the weight of the vehicle by 10% will result in 6 to 8% decrease in fuel consumption [11]. Furthermore fuel consumption is proportional to CO$_2$ emission. This means that a reduction of fuel consumption leads to less CO$_2$ emission which has of course a positive influence on the environment. Several publications show that a weight reduction of 100 kg can reduce the CO$_2$ emission with 5 to 10 g/km [12], [13], [14], [15].

This section showed the importance of weight reduction for Tribus’ seats. Less weight influences many levels of this transportation sector and will be beneficial for Tribus, its employees, the customer and the environment.

1.2.2 Diversity

As already mentioned in section 1.1, Tribus’ converted vehicles are all equipped with an aluminium profile floor system which allows both the FlexusPLUS and FlexusPRO to be positioned anywhere in the minibus. In case of the FlexusPRO, the seats are all positioned along the sides of the vehicle to ensure a maximum possible wheelchair environment when the seats are transformed. In Figure 1.3 on the facing page the two functional modes of the FlexusPRO are shown.
During the rest of this report the seating position of the seat will be addressed as mode 1 (1.3a) and the position of the transformed seat, which creates the necessary wheelchair space, as mode 2 (1.3b).

(a) Functional mode 1  
(Transportation of 8 ambulant people)  
(b) Functional mode 2  
(Transportation of 4 wheelchair occupants)

**Figure 1.3:** Functional modes of the tip seat

The flexibility of using different aluminium floor profiles to create any desired floor layout and the advent of the tip seat introduced a wide range of seat positions that led to an almost similar range of seat variants. This diversity can be explained by the different seat types and seats positions, the different vehicles and the various track gauges.

The difference between the *FlexusPLUS* and the *FlexusPRO* is that the latter has a transformation device (swivel) that enables the rotation of the seat package relative to the base frame of the seat (Figure 1.2 on page 4). Because this swivel is mounted on the base frame of the seat, two different frame heights are introduced in order to maintain the same seating height for the *FlexusPLUS* and *FlexusPRO* seats. On top of that, a special bracket is needed to position the tip seat above the wheel arches of the bus. The problem with Tribus’ current wheel arch bracket is that the positions of the seats on this bracket are fixed. This is a big disadvantage because every different seat position induces an additional bracket. In addition to these fixed positions, the gusset plates of the wheel arch bracket are too large. Due to the diversity of wheel arches from the different vehicle brands, one ‘standard’ bracket cannot be used, once more inducing the need for supplementary brackets. In Figure 1.4, a variant of a wheel arch bracket is shown together with some base frames of the *Flexus seats*.

The *Flexus* seats can be used on different floor systems that all have different track gauges varying from 95 mm to 156 mm. Tribus currently has a different base frame and wheel arch bracket for each of these track gauges. Together with the two shoulder belt positions (left side or right side) all these variations causes unfavourable procurement logistics which is not cost effective.

In table 1.1 all the component variations of the *Flexus seats* are shown which is a result of the different types of seats, seat positions, different shaped wheel arches and the various track gauges.
gauges. However, the cause of these component variations lies in the engineering of the entire seat. New and innovative solutions can reduce these variations tremendously which makes it possible to reduce costs.

Table 1.1: Component variations of the *Flexus* seats

<table>
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<th>Component</th>
<th>Variants</th>
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<td>Seat</td>
<td>4</td>
</tr>
<tr>
<td>Base frame</td>
<td>8</td>
</tr>
<tr>
<td>Wheel arch bracket</td>
<td>11</td>
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### 1.2.3 Comfort

In recent years the size of wheelchairs show an upward trend line where comfort for the occupant has become increasingly important. The size of the minibus, however, did not increase proportionally which makes it harder for the transporter to transport the same amount of wheelchair occupants within the same amount of time. In Figure 1.5 on the facing page the most inner point of the seat in mode 2 is indicated with a red line, showing that due to the current design of the *FlexusPRO* the maximal available width in the vehicle is reduced with respect to the base frame of the seat. As a result of this reduction the lateral space in the vehicle cannot be optimally used which is unfavourable for the transporter but also for the wheelchair passengers who might be positioned very close to a seat when transported side by side.

Figure 1.5 also shows that the height of the *FlexusPRO* seats is approximately similar to the eye level of the wheelchair occupant, which means that the seats obstruct an unhindered view to the outside of the bus. Moreover, when all seats are transformed into functional mode 2, hardly any view outside the vehicle is possible which gives the disabled passenger a sense of discomfort.

Besides the drawbacks in the design and construction of the *Flexus* seats, the swivel of the *FlexusPRO* has its shortcoming in the stiffness discrepancy between the two functional modes. Because the base frame of the seat is positioned eccentrically with respect to the seat package, a moment is introduced in the swivel caused by the weight of the seat. When the seat position is transformed from mode 1 to mode 2, the loads on the swivel move from the lateral plane
1.3 Problem definition

Tribus is aiming to offer the customer a multifunctional minibus that is able to transport ambulant people, wheelchair occupants or a combination of these passengers. The vehicle needs to be optimally equipped to provide the transporter maximal transportation opportunities for each passenger. Because the minibus and the floor system are considered as facts, optimisation for these buses can only be obtained by optimising the seating system.

The previous sections made it clear that despite the benefits of the tip seat, Tribus’ FlexusPRO has its restrictions that influences many levels of the transportation sector. This brings us to the problem definition of this graduation project:

Tribus’ tip seat FlexusPRO does not provide an optimal design that benefits all levels of the transportation sector. A redesign of the seat needs to result in a lightweight seating system that allows optimal procurement logistics and offers an increased comfort perception of the occupants without compromising the trans-
CHAPTER 1. INTRODUCTION

The main criteria for this new generation tip seat are stated below:

- **30% reduction of production costs;**
  
  In order to compete with other vehicle converters and seat manufacturers the production costs has to be reduced with at least 30%.

- **30% weight reduction;**
  
  A weight reduction of 30% will result in a seat weight that one is still allowed to lift to prevent any health damage [10].

- **10% increase of lateral wheelchair space;**
  
  Because the *FlexusPRO* seat in mode 2 is tilted a bit to the inside of the vehicle, the lateral wheelchair space, with respect to the most inner point of the seats, has to increase with at least 10% (120 mm), to show an overall improved wheelchair area with respect to the competitive seats.

- **20% increased view outside for the wheelchair occupant.**
  
  The seat in mode 2 is currently covering more than 70% of the window area of the vehicle, which gives the wheelchair occupant a claustrophobic feeling. The covered window area must be reduced with at least 20%, which is a (seat package) height reduction of at least 130 mm, to provide the disabled passenger a better view outside and an improved comfort perception.

The new seat will show improvements on many levels that will benefit Tribus, its employees, the transportation companies, the driver, the passengers and the environment.

1.3.1 Confinement

To reach the goal mentioned in the previous section, the design problem of the tip seat will be divided into separate subproblems where seating position mode 2 is the focus of this graduation project. This means that the transformation system is elaborated in order to acquire more lateral space and view outside for the wheelchair occupant, and to ensure a noise free driving experience. However, to obtain a good design, a complete concept of the new tip seat needs to be proposed where every aspect of the seat is able to fulfil the design requirements as stated in Appendix B.

The result of this report will be a concept of the complete tip seat, based on a morphological analysis, where the transformation system is elaborated in detail. The system will be assessed with respect to the design requirements and is supported by means of calculations and technical drawings. Finally, recommendations for the continuation of this project will be made.
Chapter 2

Morphological analysis

There are multiple solutions for transforming a seat in order to create the necessary wheelchair space in a minibus. By using the morphological analysis [1], possible solutions for the transformation are explored to obtain the most suitable tip seat concept for Tribus. This chapter will discuss the results of the morphological scheme for this new concept and finally explains the benefits of the new design with respect to the FlexusPRO.

2.1 Function block diagram

As discussed in chapter 1, the main criteria for the new tip seat are weight reduction, reduction of the production costs and an increased lateral space in combination with an increased view outside for the wheelchair occupant. Throughout this entire project it appeared that several requirements adversely affect each other. For instance, the weight reduction in combination with the strength requirements [2], [3], [4] conflict with the requirement of reducing the production costs, because it requires the use of high strength material. To prevent this, components will have to be reduced in combination with innovative production techniques to realize the goal of maintaining the strength, while reducing weight and production costs.

To understand the functionalities of the tip seat a function block scheme is used. The transformation from mode 1 to mode 2 is divided into separate function blocks which is shown in Figure 2.1. For each function possible solutions are found and arranged in a Morphological scheme, which can be found in Appendix E.1. Figure 2.1 shows all function blocks in series, but the challenge is to combine functions (parallel blocks) to reduce the amount of operations and therefore the time required for transformation.

![Figure 2.1: Function block diagram of the FlexusPRO](image-url)
(a) Concept A

(b) Concept B

(c) Concept C

Figure 2.2: Morphological transformation concepts A, B and C

The different solutions for each function in the morphological scheme (E.2) resulted in three transformation concepts that are shown in Figure 2.2.

Figure 2.2a shows a tip seat where the seat pan is lifted, the backrest is tilted forward and the headrest is moved down, which eventually creates a compact seat package that is rotated 90 degrees around its vertical axis. After this rotation, the benefit of tilting the backrest forward becomes clear and shows an improvement of the lateral space for the wheelchair passenger. The outside view for the wheelchair occupant is improved by the vertical movement of the headrest.

Concept B in Figure 2.2b shows the tip seat of Tribus’ main competitor. By moving the headrest down and folding the backrest on the seat pan, a seat package is created that is rotated 90 degrees around its horizontal axis. The benefit of the rotation around this axis is that the entire seat package remains below the windows of the vehicle, which gives the wheelchair occupant a clear view outside. The drawback however, is that this seat package requires more space in longitudinal direction, which limits the positioning of the seats.

Figure 2.2c shows the third transformation concept of the tip seat, where the movement of the headrest and the backrest are similar to that of concept B. Instead of a rotation however, the entire seat package is translated in vertical direction in order to realize a final position where the seat package is flush with the floor of the vehicle. Besides an unhindered view outside for the wheelchair occupant, this concept realizes an optimal lateral wheelchair area that is equal to the entire floor area of the vehicle. However, this concept affects the current floor principle which will have major consequences for the engineering costs.

The three transformation concepts are rated in accordance with the list of design requirements stated in Appendix B. A distinction has been made between the requirements with respect to manufacturing and usage of the seat. The result of this rating is visualized in a so called S-diagram (Figure 2.3 on the next page), where the relative ratings of manufacturing aspects are plotted against the relative ratings of usage aspects.
2.2. NEW TIP SEAT CONCEPT

Figure 2.3: S-diagram of the rating of tip seat concepts A, B and C

To select the best concept one would like to have high ratings around the diagonal. Therefore, boundary conditions are introduced where each aspect should have a rating of at least 60%, while the minimal combined rating should be 70%. The diagram directly shows that concept A is preferred. The concepts and ratings can be found in Appendix E.1.

2.2 New tip seat concept

Although concept C offers the best solution for the required increase of lateral wheelchair space and view outside for the wheelchair occupant, the other requirements of reducing both weight and production costs are not met, which again illustrates the adverse affect of the different requirements. The effect of this concept on the current floor principle also affects the marketing of the seat.

More than 95% of the multifunctional transportation vehicles are equipped with floor mounted seats. A different fixation between the vehicle and the seat would prevent marketing of the seat to other companies. This is also why the morphological scheme does not show for instance, wall or ceiling mounted seats.

The S-diagram shows that concept A is the best floor mounted tip seat concept considering both manufacturing and usage aspects. The transformation concept distinguishes itself from Tribus’ main competitor and creates the extra required lateral space by the angular movement of the backrest. The required increased view outside for the wheelchair passenger is realized by the translation of the headrest.
2.2.1 Backrest

The ability of tilting the backrest forward will increase the maximal available width in the vehicle. The lateral space will be defined by the base frame of the seat instead of the backrest. Tilting the backrest maximally forward, so that rotation of the seat from mode 1 to mode 2 is still possible, will increase the lateral space above the base frame even more, which is illustrated in Figure 2.4. Figure 2.4b shows that this extra space above the base frame will benefit the seating comfort of the wheelchair occupant around the arms. By minimizing the width of the base frame and seat package in mode 2, the available width in the vehicle can be optimized for wheelchair transportation.

Moreover, an optimization of the thickness of the backrest also has a positive effect on the available seating space for the passenger and the longitudinal positioning of the seats. The space between the backrest of a seat and a seat in front must be at least 650 mm, measured at seating height [7]. Reducing the thickness of the backrest will increase the distance between the seats which offers more seating comfort for the passenger. The transporter can also decide to maintain the above mentioned distance of 650 mm, which means that the positioning of the seats becomes more flexible in longitudinal direction and additional space can be obtained for e.g. luggage. However, a reduction of the thickness of the backrest might have its influence on the comfort perception of the passenger, which is again a contradiction that has to be taken into account in the new design.

![Figure 2.4: Concept A shows an increased lateral space and view outside for the wheelchair occupant, with respect to the FlexusPRO](image)

2.2.2 Headrest

The most upper point of the headrest of the FlexusPRO is approximately at a similar height as the eye level of the wheelchair occupant, as can be seen in Figure 2.4a. A vertical translation of the headrest from mode 1 to mode 2 therefore directly improves the view outside for the disabled
2.2. **NEW TIP SEAT CONCEPT**

passenger. Research on the current commercial vehicles showed that a vertical adjustment of the headrest of 210 mm is possible (Appendix G). The *FlexusPRO* is currently covering 70% of the vehicle window. A vertical displacement of 210 mm will result in an increase of window area by almost 33%. Moreover, this reduction benefits the wheelchair occupant’s view outside even more, because he is also able to look down as indicated in Figure 2.4b. Together with the extra lateral space that concept A is offering, this new concept will give the wheelchair occupant a less claustrophobic feeling which improves his comfort perception.

These new functionalities improve the comfort of the passengers as well as the ease of use for the transporter, regarding the positioning of the wheelchair occupants. However, the new concept is more complex with respect to the *FlexusPRO*. Extra moving parts require additional fixations which could have a negative influence on the weight, production costs and ease of operation regarding the transformation from mode 1 to mode 2. During the design of the new seat, these repeating contradicting aspects therefore need continuous attention.

Besides the design of a new system for gaining extra lateral space in the vehicle, a new design for the swivel device of the seat is needed to reduce the weight and prevent any unpleasant sounds during driving caused by excessive vibrations as a result of the stiffness discrepancies explained in paragraph 1.2.3. These two devices will be elaborated in the next chapters.
Chapter 3

Tilting device

All vehicles with a M1 classification require seats with three point safety belts. Because the Flexus seats can be positioned anywhere in the vehicle, the three point belts are all integrated in the seats. The upper third point of the safety belt is fixed to the backrest, which means that during a frontal impact of the vehicle, the tremendous loads from the occupant (caused by the deceleration) [3] will be transferred through the backrest into the locking mechanism of the tilting device.

The angular movements of backrests in commercial car seats are usually performed by recliners. The locking mechanism of these recliners is based on gear principles to withstand the above mentioned loads from the occupant. This results in additional production costs and weight, which of course is not wanted. Furthermore, the required angular movement of the backrest, that provides the desired lateral wheelchair space, introduces an additional undesired operation that is needed to transform the seat to mode 2.

This chapter however, shows an innovative solution for the angular movement of the backrest, that does not need an additional locking mechanism and even reduces the amount of operations needed for the transformation.

3.1 Toggle clamp

As already discussed in chapter 2 the additional tilting device improves the comfort of the disabled passenger, but introduces an extra moving component on the seat that could have a negative influence on the production costs and ease of operation regarding the transformation. By combining multiple movements during the transformation between the modes, the amount of required operations could remain the same with respect to the FlexusPRO. A combination of the angular movements of the backrest and the seat pan is found, which resulted in a mechanism based on the principle of a toggle clamp.

In Figure 3.1a on the next page a horizontal toggle clamp is shown. A toggle clamp is normally used to amplify a relatively low operator input force to a high output clamping force in order to firmly hold a work piece [17]. It is however, not the force that is interesting for the seating system, but the mechanism that realizes the angular movement in combination with a firm hold.
CHAPTER 3. TILTING DEVICE

The mechanism of a toggle clamp is based on the over-centre principle, which is illustrated in Figure 3.1b. It is a geometrical linkage system of bars and joints that are moved in an over-centre position preventing the clamp from opening. The holding force of the toggle clamp depends on the strength of the linkage system. This system will be further elaborated in section 3.2.2.

By creating a similar link between the backrest and the seat pan, based on this over-centre principle, two operations could be combined and fixation of the backrest would be realized by the geometry, instead of an additional locking device.

3.2 Tilting operation

As discussed in the previous section, the functionality of the toggle clamp can be used to fold the backrest and the seat pan within one operation and even fix the backrest in functional mode 1. However, the pivot points of the clamp in Figure 3.1a realize an equal angular movement, whereas the movements of the backrest and the seat pan are not similar. Before designing the right pivot positions for the seat, at first the shape of the backrest and seat pan are determined to provide a comfortable seating for the user.

3.2.1 Comfortable seating

Weight reduction is an important requirement for the seat as discussed in section 1.2.1 on page 5. By reducing the thickness of the foam for both seat pan and backrest, weight can be saved and a more compact seat package can be realized, which improves the lateral wheelchair space. However, the reduction of foam must not have an influence on the seating comfort. To achieve this, the right choice of foam in combination with a shape of the seat that suits most of the
3.2. TILTING OPERATION

(a) A special seat developed by Staarink for his research into measurable criteria for good sitting postures

(b) Definition of the angles that define the sitting posture in the sagittal plane

Figure 3.2: Images from Staarink’s research

passengers, requires less foam in order to give at least a similar level of comfort with respect to the Flexus seats.

The Flexus seats in the minibus are used for a large variety of passengers. One would expect that it is hard to find a shape that suits most of these people. However, Staarink [9] showed that a comfortable shape of the backrest and seat pan is not that individual as one might think.

In 1997 Staarink started a research into measurable criteria for good sitting postures. A special seat has been developed that is shown in Figure 3.2a. The seat made it possible to change different variables and show the individual curvature of the spine at the back. From his experiments with the seat and the results of Grandjean’s research The Development of a Rest Chair Profile for Healthy and Nostalgic People in 1969, he concluded that a relaxed individual preferred posture is less individual as expected. Staarink found out that a stable sitting posture occurs at an angle of $115^\circ$ ($\varphi + \alpha$ in Figure 3.2b), where stability of the body is reached. He showed that the phenomenon ‘head in balance on the body’ lies on top of the hierarchy of comfort perception.

Wotzka did research on an auditorium seat by testing different seat configurations with a large number of subjects. The result of this seat is shown in Figure 3.3a. Staarink showed that this seat has a functional angle of the backrest of $115^\circ$ conform his definition in Figure 3.2b. The shape of the Wotzka seat is used as a guidance for Tribus’ new tip seat, because, according to Staarink’s research, it should provide a good comfort perception and also realizes a good fit between the seat pan and the backrest in functional mode 2 as shown in Figure 3.3b. The objective is to define the pivot points of the backrest and the seat pan in such a way that an over-centre position is reached in functional mode 1, as described in section 3.1, and a good fit between these components is achieved in mode 2 that realizes an optimal wheelchair area.
CHAPTER 3. TILTING DEVICE

(a) Wotzka’s auditorium seat with a functional angle of the backrest of 115° as defined by Staarink
(b) Shape of the Wotzka auditorium seat that is used as a guidance for Tribus’ new (tip) seats in both functional modes

Figure 3.3: Wotzka’s seat shapes that have a functional angle of the backrest of 115°, where stability of the body is reached according to Staarink’s research

3.2.2 Pivot points

In Figure 3.4 the new shape of the seat is illustrated. It gives an impression of the movements of the backrest and seat pan when the seat is transformed from functional mode 1 to mode 2. The detailed illustrations of the pivot points, shown in Figure 3.5, clearly show the stages along the transformation, from clamped to unclamped position, similar to the toggle clamp principle described in Figure 3.1b.

The pivot points are chosen carefully to ensure the correct movements of the backrest and the seat pan. One can see in Figure 3.4 that the backrest moves slightly rearwards, before tilting forward. This movement together with the principle of the mechanism will be explained below in further detail.

In Figure 3.5 one can see the three stages of the mechanism in detail. As already said earlier the objective is to define the pivot points of the backrest and the seat pan in such a way that an over-centre position is reached in functional mode 1 and a good fit between these components is achieved in mode 2, to realize an optimal seat package that would increase the lateral wheelchair space.

The over-centre position is reached when pivot point 3 remains on the left side of the red dotted line between pivot point 2 and 4 (line 24). When a load is exerted on the diagonal safety belt, the backrest (green part) wants to tilt forward around pivot point 1. This will result in
3.2. TILTING OPERATION

Figure 3.4: Transformation impression of the new seat from functional mode 1 to mode 2, based on the over-centre principle. The illustrations show the stages from the over-centre/clamped position (mode 1) to the unclamped position (mode 2). The first stage shows the shape that corresponds to Wodtka’s seat (dotted line). The dotted lines shown in the other stages are the new seat in functional mode 1 to illustrate the movements of the backrest and seat pan during the transformation.

A downward load on point 2 which consequently results in the angular movement of point 3, around pivot point 4, away from line 24. However, this movement is prevented by the seat frame (magenta part), that encloses the bottom part of the seat pan (blue part).

Increasing the distance from point 3, perpendicular to line 24 will benefit the safety in order to prevent the backrest from tilting forward, considering possible deformations during a frontal impact. Nevertheless, this distance is bounded by the acceptable rearward movement of the backrest when the seat configuration changes from the over-centred state to the dead centred state. The distance from point 3, perpendicular to line 24, is therefore restricted by 10 mm in mode 1. This specific distance ensures a safe clamped position in functional mode 1, without an excessive rearward movement of the backrest when the seat is transformed to mode 2.

Figure 3.5: Detailed illustration of the tilting mechanism in the stages over-centre/unclamped position, dead centre position and unclamped position. The green part represents the backrest, the blue part the seat pan and the magenta part the seat frame that connects the backrest and the seat pan.

The position of all 4 pivot points are chosen in such a way that the backrest and seat pan have a good compact fit in functional mode 2 and ensures a safe clamped position in mode 1, without an excessive rearward movement of the backrest in the first stage of the transformation from mode 1 to mode 2. The design of this mechanism resulted in a first physical prototype to check the feasibility of the system. The images of this prototype are shown in Figure 3.6.
CHAPTER 3. TILTING DEVICE

Figure 3.6: The first physical prototype of the tilting mechanism in the over-centre, dead centre and unclamped state

The results were promising and all benefits mentioned before were confirmed. Tribus decided to continue with the development of this mechanism in order to do a physical pull test and eventually start series production. In Appendix C a detailed drawing of the position of the pivot points for the new tip seat can be found, based on the over-centre principle of the toggle clamp. Furthermore, images of the first prototype of the tilting mechanism are shown.

### 3.3 Seat improvements

The design of the tilting mechanism has led to multiple improvements for the new *FlexusPRO*. First of all, Figure 2.4 on page 14 already showed that the tilting mechanism improves the lateral space for the wheelchair occupant, especially around the shoulders.
3.3. **SEAT IMPROVEMENTS**

Secondly, a new shape of the seat is determined based on Wodtzka’s auditorium seat where, according to Staarink’s research, stability of the body, and the associated comfort perception, is reached. The improved shape, in combination with the right type of foam, makes it possible to reduce the thickness of the foam, without losing any seating comfort. A reduction of foam reduces both costs and weight. Because the shape of the seat also ensures a good fit between the backrest and the seat pan in functional mode 2, the combination with a reduced foam thickness results in an optimal seat package that will increase the lateral wheelchair space even more, which are the main requirements.

Another benefit of reducing the foam thickness is a thinner backrest which increases the possible seat positions in the vehicle in longitudinal direction and directly improves the multifunctionality of the vehicle. This has to do with the imposed minimal seat depth which is explained in Appendix B on page 48.

Finally, the tilting mechanism itself resulted in an innovative design for the tip seat. The system is based on the over-centre principle of the toggle clamp, which provides a simultaneous movement of the backrest and seat pan during the transformation from mode 1 to mode 2 and vice versa. This means that the extra tilting functionality of the backrest has no consequences for the amount of operations and required time for transformation, which are requirements stated in Appendix B.

Furthermore, the mechanism automatically locks the movement of the backrest in functional mode 1 (over-centre state), when the seat pan is moved down. This locked position is fully achieved by the geometry instead of additional locking devices, which makes this solution unique, because it has hardly consequences for the production costs and weight, despite the required additional functionality of the moveable backrest. A first prototype of this mechanism underlines all benefits that are mentioned above and Tribus decided to continue with the development for series production.

One has to keep in mind that the construction of the seat is changed with respect to the FlexusPRO and the linkage between the backrest and the seat pan needs to have a robust design to withstand the forces that are applied on the backrest of the seat according to directive 76/115 EEG [3].
Chapter 4

Swivel device

Tribus’ current swivel is an effective and easy to use device to transform the seat from functional mode 1 to mode 2 within only a few seconds. However, as discussed in section 1.2.3, this swivel has its shortcomings with respect to the uniform stiffness between the two functional modes, which causes excessive vibrations during driving, resulting in an unpleasant sound for all occupants. Besides this stiffness discrepancy, the weight of the swivel is also an issue, knowing that its 4.8 kg is approximately 15% of the total weight of the seat. All drawbacks of Tribus’ current swivel are elaborated in Appendix D. In this chapter, the new design of the swivel is elaborated which shows improvements for all drawbacks of Tribus’ current swivel.

4.1 FlexusPRO’s swivel

Section 1.2.1 showed that a weight reduction of the Flexus seats is important for many parties in the transportation sector. The seat is therefore divided into different components to quantify their influence on the total weight of the seat, which can be seen in Table 4.1 on the following page. One can see that three components of the seat are responsible for more than 80% of the entire seat weight, which are the base frame, the swivel and the backrest. A weight reduction for these three components will be the most effective with respect to the entire seat weight reduction. In Figure 4.1 Tribus’ current swivel is shown which is, despite its relatively small size, already responsible for 15% of the seat weight.

(a) Isometric view from the top of the swivel  
(b) Isometric view from the bottom of the swivel

Figure 4.1: Tribus’ current swivel for the FlexusPRO weighing 4.8 kg
Table 4.1: Quantification of the influence of the component weights on the total weight of the *Flexus* seat

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base frame</td>
<td>5 kg</td>
<td>15,7 %</td>
</tr>
<tr>
<td>Flooradapter (2 pcs)</td>
<td>1,7 kg</td>
<td>5,3 %</td>
</tr>
<tr>
<td>Swivel</td>
<td>4,8 kg</td>
<td>15,1 %</td>
</tr>
<tr>
<td>Armrest</td>
<td>1,1 kg</td>
<td>3,5 %</td>
</tr>
<tr>
<td>Seat pan</td>
<td>3,1 kg</td>
<td>9,8 %</td>
</tr>
<tr>
<td>Backrest (incl. safety belt)</td>
<td>16,1 kg</td>
<td>50,6 %</td>
</tr>
<tr>
<td>Total weight</td>
<td>31,8 kg</td>
<td>100 %</td>
</tr>
</tbody>
</table>

4.2 Swivel concept

For the design of the new swivel all drawbacks were taken into consideration. Again, a morphological approach is used that resulted in four concepts that are elaborated in Appendix E.2. Figure 4.2 shows the function block diagram of the swivel for the seat transformation from mode 1 to mode 2 and vice versa. For each function of the swivel, possible solutions are found and arranged in a Morphological scheme, which can be found in Appendix E.2.

![Function block diagram of the swivel](image)

Figure 4.3 shows the new swivel that has the highest rating with respect to the (manufacturing) requirements. Elaboration of the concept resulted in a swivel with steel quality S355, that has a total weight of 3 kg, which is a weight reduction of almost 38%. The entire swivel is designed to reduce costs and weight, resulting in only 6 items which is a major reduction of components, considering Tribus' current swivel with more than 20 items. The construction is based on machined parts that can be assembled to one rotation device with only 2 bolts. It does not require any welding which, in combination with the easy assembly, reduced the costs significantly.
4.2. **SWIVEL CONCEPT**

The device has a fixed part that is bolted to the base frame of the seat, consisting of a *swivel bottom support* (magenta part) and a *swivel bottom* (red part). The *swivel bottom support* is used as a sliding surface for the *swivel top* (green part) and the two *locking strips* (brown parts). The *swivel top* is bolted to the seat frame and has a flange that is supported by the ring of the *swivel bottom*. This support has a minimal clearance which makes the rotation possible, but assures a minimal amount of play that prevents unwanted vibrations. The rotation of the *locking disc* (blue part) is converted into a (radial) translation of the *locking strips*, which moves these strips in and out of the slots of the *swivel bottom*, to respectively prevent or realize the rotation of the seat in both functional modes. A section view of the fixed and unfixed position of the rotation device is shown in Figure 4.4. The rotation of the *locking disc* is activated by a lever which will be part of the seat frame. The operation of the swivel will be done by a handle that is situated at the side or at the top of the seat. This is decided in a later stage of the final design of the entire seat. The handle is then connected to the lever by a cable. This solution makes the operation of the swivel uniform and easy to reach. The principle is shown in section 4.3.3.

The new swivel components are analysed by a FEM analysis to check the strength of the rotation device and the restraint of the rotation, regarding the *locking strips*. This is shown in Appendix I. Also, a prototype of the new swivel is built to analyse its functionality and strength, which is shown in Figure 4.5. A physical pull test has been done with this prototype, that showed that the new swivel passed the test and even still functioned afterwards. After the
4.3 Benefits

The new swivel design proved to be exceeding all aspects of Tribus’ current swivel. This section will briefly discuss these aspects.

4.3.1 Weight

As already discussed, the new swivel weighs only 3 kg, which is a weight reduction of approximately 38%. The physical pull test showed that the swivel is very strong and even still functions after the test. More weight might be saved by changing the material of certain components or even all components when considering a high tensile aluminium. However, this requires further elaboration with respect to the stiffness and wear resistance of the components after multiple
4.3. BENEFITS

rotations. In this case, one also has to consider the aspect of the production costs to weight ratio.

4.3.2 Stiffness discrepancy

As discussed in Appendix D.2 on page 55 the construction of Tribus’ current swivel is not symmetrical. Because of this asymmetry the stiffness in both functional modes is not similar, which causes undesired vibrations in functional mode 2.

The new concept has an equal stiffness in both modes. Because the rotation of the seat from functional mode 1 to mode 2, and vice versa, is not critical, a decision has been made not to use ball bearings for this rotation in order to save weight. A sliding surface with a relative low friction enables the rotation between the two modes. However, this requires a certain amount of tolerance, which might result in undesired vibrations. The swivel is therefore designed in such a way, that two critical parts, the top and bottom disc, determine the amount of tolerance. Only the difference in thickness of the flanges of these two parts determines the amount of play of the system, which can easily be regulated by defining the level of tolerance. The other parts are irrelevant for the amount of play which will result in cheaper products. The physical prototype of the swivel also confirmed this.

4.3.3 Operation

Another drawback of the current rotation device is the accessibility of the lever for releasing the swivel, in combination with the inconsistent operation (Appendix A). In the new design for the FlexusPRO, the operation of the swivel will be performed by pulling a handle which is connected, by a cable, to a lever which will be integrated in the seat frame. The lever will be connected to the locking disc of the swivel which ensures a consistent operation with a good accessibility for the operator. A photo of this principle is shown in Figure 4.6.

4.3.4 Assembly

The assembly of the swivel is also improved. The amount of items for the new swivel are drastically reduced and no welding is needed for the assembly of this swivel, which can be realized within 1 minute. These improvements resulted in a cost reduction of €27 compared to Tribus’ current swivel, which is more than 47%. The accessibility of the bolts for fixing the swivel to both seat and base frame is also improved and can always be reached without removing other parts from the seat. This is an improvement that benefits the total assembly time of the seat and the time needed for possible repairs in the future.

On can conclude that the new swivel shows improvements on all levels of problem areas that are discussed in the sections of this chapter. Besides these improvements, it also complies with multiple requirements that are stated in Appendix B.

The simplicity of the new swivel resulted in a cost reduction of 47% and a weight reduction of 38%. The weight reduction could probably be increased even more after further evaluation of the components. The abovementioned reductions exceeded the requirements stated by Tribus, who decided to use this swivel principle in their future seat.
The new swivel has even more benefits that are not mentioned in the previous sections because they depend on the design of the entire seat. Both outside dimensions and height are reduced. The reduced outside dimensions of the swivel could increase the lateral wheelchair space, providing that the dimensions of the entire seat package also remains within these outside dimensions of the swivel.

The reduced height of the swivel ensures an almost equal seating height for the FlexusPRO and FlexusPLUS, which reduces the need for multiple base frames. An equal seating height for both seats can be realized by a standard base frame where the minimal height of the swivel can be compensated by a low weight spacer for the FlexusPLUS. In short, a reduction of components and weight for the FlexusPLUS.
Chapter 5

Discussion

Tribus’ multifunctional minibuses are equipped with FlexusPRO tip seats that enable an easy and fast transformation between the transportation of ambulant people and wheelchair passengers. Despite the benefits of its functionality the FlexusPRO seats have some limitations regarding weight, variation of components and comfort. A morphological approach is used to analyse the functionality of the seat and to find the best design for the tip seat with respect to the design requirements that are stated by Tribus, customers and legislation. This chapter discusses the results of the two functionalities of the seat that were elaborated in the previous chapters.

5.1 Backrest adjustment

The morphological approach for analysing the tip seat resulted in a seat with a forward tilting backrest in order to create additional lateral space for the wheelchair passenger. Figure 2.4 on page 14 clearly shows the improvement of comfort for the wheelchair occupant, especially around the areas of the head and arms. However, this is an additional functionality with respect to Tribus’ current tip seat which means additional components and additional costs.

The main criteria for the new tip seat, in order of importance, are a reduction of costs, weight, required space and height of the seat in functional mode 2. An adjustable backrest, as foreseen, would imply that this new functionality contradicts 50% of these requirements. An additional locking device is needed to prevent the backrest from tilting, especially in mode 1 which has its influence on the costs and weight of the entire seat, or not? In the following section, this question will be answered.

5.1.1 Production costs

In chapter 3 a new mechanism for the seat transformation is elaborated, based on the toggle clamp. The system uses the over-centre principle to restrain the movement of the backrest in mode 1. Because the strength of this type of locking mechanism is found in the combination of links and the position of the joints, the design barely requires extra components. This means that despite the extra tilting functionality, the new design hardly effects the production costs
and weight. To lower the production costs, one has to look for production techniques that reduces labour time to produce the seat components and facilitates the assembly of the entire seat.

5.1.2 Transformation

Another benefit of the over-centre principle for the tip seat, is that the seating angle and fixation of the backrest is performed automatically which enhances the ease of use for the transformation with respect to commercially available backrest adjusters. Furthermore, the angular movements of the backrest and seat pan are performed simultaneously, which means that the extra tilting functionality of the seat has no influence on the transformation time between the functional modes, compared to the current FlexusPRO seats.

In summary, the new mechanism for the angular movement and restraint of the backrest appears to be a very suitable solution for the new FlexusPRO tip seat. The new feature of tilting the backrest forward provides an increased sense of comfort for the wheelchair occupant which is a large improvement. Furthermore, the strength of this mechanism fully depends on the geometry of the backrest and the seat pan which excludes the need for additional devices and corresponding operations. This means that the additional feature hardly has consequences for the production costs and weight. Finally, the combined movement of the seat pan and the backrest has no influence on the transformation time which is also one of the requirements stated in Appendix B.

5.2 Swivel

The angular movements of the backrest and the seat pan are the first operation to transform the new tip seat from mode 1 to mode 2. The second operation is the 90 degrees rotation of the seat package. The rotation device (swivel) of the FlexusPRO has some drawbacks with respect to its weight, stiffness and operation, which requires an improvement on all aspects. In chapter 4 the swivel is elaborated and the new design is realized based on the morphological approach. The improvements will be discussed in the following sections.

5.2.1 Production costs

As already discussed, the reduction of the production costs is the most important design requirement for the new tip seat. This normally means that the manual labour time has to be reduced. The design of the new swivel components is ideal for machining and the assembly can be realized without welding and within a short time, which reduces the production costs enormously.

Moreover, the components for the new swivel are reduced with respect to the current swivel. Because the transformation from one mode to the other requires only a 90 degrees rotation, the two, relatively expensive, ball bearings are replaced for a good (lubricated) sliding surface which is also beneficial for the production costs, without affecting the ease of operation.
The small height of the swivel rules out the need for an extra base frame with respect to the height compensation for fixed and tip seats as discussed in section 1.2.2. Because the effective height above the base frame is approximately 20 mm, the height difference can be compensated by a relatively light and low cost plastic spacer, which improves the procurement logistics and therefore benefits the production costs.

These improvements have ensured that the production costs for the new swivel are reduced by 47% which is far above the required 30%.

5.2.2 Weight

The second most important requirement is the 30% weight reduction. The replacement of the two ball bearings for a lubricated sliding surface not only influenced the production costs, but also realized a lower weight for the complete swivel assembly. In combination with the new design the entire swivel weighs 3 kg which is a reduction of 38%.

5.2.3 Comfort

The backrest adjustment already showed an amelioration of comfort for the wheelchair occupant in lateral direction. Due to the rotational symmetric construction of the new swivel, the comfort for all occupants is improved. The symmetry provides an equal stiffness in both functional modes which excludes the excessive vibrations and associated noise in mode 2.

The operation of the swivel is moved to the outside of the seat which shows an improvement of accessibility. The lever for operating the current swivel is positioned underneath the seat which only becomes visible, and within reach, when the operator bends forward. Another drawback of the current swivel is the different operation for left and right seats. The new design solved this problem inside the seat which resulted in a uniform operation for all seats.

One can conclude that the design of the new swivel showed improvements on all aspects without any concession. If the design of the entire seat keeps following this trend, the stated goals with respect to production costs and weight reduction can be realized and even be exceeded.

5.3 Recommendations

During this thesis, the design of other components are also taken into consideration with respect to the interaction with the swivel. In section 1.2.2, the diversity of seat components is discussed and this section gives some recommendations to reduce the variety of the base frames of the seat and the wheel arch brackets. Finally, the process to market introduction will be discussed.

5.3.1 Base frame

Tribus currently has eight different kind of base frames. This variety is caused by the four different track gauges and the height difference between the FlexusPRO and FlexusPLUS seats. At first the possibility for standardization of the track gauge was explored, but this appeared to be impossible because of three different suppliers for the aluminium floor profiles. Nevertheless,
CHAPTER 5. DISCUSSION

the different track gauges could be reduced from four to three which are 95 mm, 115 mm and 121 mm. These variations can be compensated by slots in the base frame which could reduce the variety of frames from eight to only two base frames, that only differ in height because of the compensation for the seating heights with respect to the *FlexusPRO* and *FlexusPLUS* seats.

However, the height of the swivel is also reduced which reduces the height difference of the remaining two base frames. This minimal height difference can be compensated by a plastic spacer which hardly has consequences for the weight and results in only one type of base frame for all seats. A more cosmetic solution could be to design the base frame such that the swivel is integrated inside the frame and the difference between a *FlexusPRO* seat and a *FlexusPLUS* seat is not noticeable any more.

5.3.2 Wheel arch bracket

The wheel arch brackets are also widely represented when it comes to variations. These variations are caused by the fixed seat positions on the bracket. For the design of the new wheel arch brackets, the seats should have the possibility to be positioned on variable locations on the bracket. A solution is found to reduce the eleven wheel arch brackets to one bracket for all seat configurations.

The construction is based on two legs, a specific aluminium extrusion profile and a sliding adapter as shown in Figure 5.1. The ‘thin’ swivel in combination with the extrusion profile makes it possible to realize one height for the wheel arch bracket that fits the most common vehicles.

![Figure 5.1: A new design for the future wheel arch bracket that covers all track gauges and seat positions](image)

The benefit of the sliding functionality is the fact that the seat can be fixed on different locations in longitudinal direction, which brings the variety of wheel arch brackets back to a single bracket that fits ‘all’.

Another benefit of the sliding adapter is the possibility to fix the seats on the wheel arch bracket inside the vehicle, instead of positioning the entire, relatively heavy, bracket including
5.3. **RECOMMENDATIONS**

the seats. This saves a lot of lifting weight which is favourable for the employee that has to fit all seats inside the vehicle.

5.3.3 **Process to market introduction**

This thesis resulted in a new tip seat concept where the transformation device is elaborated. As already discussed, the swivel has been calculated by means of a FEM analysis and tested by a physical pull test. The results were promising and Tribus is currently refining the design to optimize the weight and define the production process for series production.

The new tilting mechanism that uses the over-centre principle is further elaborated in order to build a prototype that will also be pull tested. The results of this pull test will be used for refining the design in order to start series production of the seat construction.

A new base frame and wheel arch bracket, as shown in Figure 5.1, are designed to reduce component variations and improve procurement logistics. The new concept suffices with only one base frame and one wheel arch bracket instead of eight and eleven respectively.

Furthermore, a new suspension material for the seat pan and the backrest, called Dymetrol, will be investigated. This material makes it possible to reduce the foam thickness without losing seating comfort. This reduces both costs and weight.

All aspects of Tribus’ new tip seat will be elaborated in detail as proposed by this thesis in order to start a pre-production at the end of September this year. When all improvements are taken into account, one can conclude that the new tip seat will meet all 36 requirements as stated in Appendix B!
Chapter 6

Conclusion

The FlexusPRO is a multifunctional seat that meets the highest safety requirements. The current drawbacks of the seat however, asked for a new design where the main criteria are 30% reduction of production costs, 30% weight reduction, a 10% improvement of available lateral wheelchair space and a 20% increased view outside for the wheelchair passenger. Because of the M1 safety requirements, it has not been easy to meet all these criteria. The construction of the current FlexusPRO is quite basic, which means that weight reduction and low costs does not have a proportional relationship. However, new designs prove otherwise, especially for the swivel.

The morphological approach for the entire seat resulted in a seat concept that improves the view outside for the wheelchair passenger and the available lateral wheelchair space. The improved view is acquired by the separate headrest that is lowered during the transformation to mode 2. Research on the current commercial vehicles showed that a vertical displacement of the headrest with 210 mm is possible, which would increase the outside view for the wheelchair occupant with at least 33%.

The improvement of lateral wheelchair space is reached by tilting the backrest forward when transforming the seat from functional mode 1 to mode 2. The increased lateral dimension, as a result of the tilting backrest, manifests itself especially around the arms of the wheelchair occupant. However, the overall increased lateral space depends on the entire seat design, where the base frame of the seat will be leading. Because the base frame of the seat is not part of this project, a specific percentage of the improvement is not yet known. Nevertheless, an improvement of at least 10% can be realized and will even exceed the requirements around the arms of the wheelchair occupant.

The drawback of the tilting backrest is the fact that the seat became more complex, which eventually is inevitable considering the requirements. However, the increased complexity did not resulted in the expected increase of costs due to an additional locking device, that needs to prevent the angular movement of the backrest. The angular movement is locked by the geometry of the backrest and seat pan, which is based on the over-centre principle of a toggle clamp. The geometry ensures an automatic locking of the backrest when the seat pan is down. The new mechanism appeared not only to be cost effective, but also prevented additional operations because of the simultaneous movement of both seat pan and backrest. A physical prototype of
this tilting device underlined all benefits and proved to work as expected. The new mechanism therefore complies with all requirements that are stated, and will be implemented in Tribus’ new tip seat.

The new swivel is designed to reduce production costs and weight. It is stiff in both functional modes, with a minimal weight in combination with the required strength to meet the EU requirements. Also for this design a prototype is made, that concludes that the new swivel design meets all of the requirements and even passed the physical pull test successfully. The simplicity of the new swivel resulted in a cost reduction of 47% and a weight reduction of 38% which exceeds the requirements.

When the entire project of the new tip seat continues to follow the trend of this graduation project, not only the required cost and weight reduction can be realized, in combination with an increased wheelchair space and view outside for the wheelchair occupant, but all 36 requirements as stated in Appendix B will be met!
Appendix A

*FlexusPRO*

In this appendix the *FlexusPRO*, its components and its functionality is elaborated by means of illustrations and brief descriptions.

The *FlexusPRO* is Tribus’ first tip seat. It consists of a steel base frame, a rotation mechanism called a swivel and a seat with integrated three point safety belt. The seat can also be positioned above the wheel arch where the steel base frame is replaced by a steel wheel arch bracket that can offer two seat positions. In Figure A.1 these FlexusPRO assemblies are shown.

One of the drawbacks of the *Flexus* seats is the large variety of frames that are used to make
the connection from the seat to the floor. There are four reasons that induce these variations.

At first, there is a height difference between the base frame of a FlexusPLUS seat and that of a FlexusPRO seat. The FlexusPLUS seat is a fixed seat, which means that it cannot rotate around the base frame of the seat. The FlexusPRO seat is a tip seat, which can rotate around the base frame of the seat by means of the additional swivel. Because of this additional component, already two different base frames are introduced to obtain a similar seating height for both Flexus seats.

Secondly, the tip seats need to be positioned as far as possible to the side wall of the vehicle to obtain a maximal wheelchair space when the seats are transformed into mode 2. This means that an additional frame, the wheel arch bracket, is needed to position the seats above the wheel arch of the minibus.

Thirdly, the construction of the wheel arch bracket causes additional frame variations because of the fixed seat positions. One can imagine that multiple variations are introduced dependent on the amount and position of seats on the bracket.

Finally, the vehicle is equipped with a floor system based on aluminium profiles that can be assembled to form any desired floor layout. Some of these profiles have an airline track, which is a specific rail with a continuous pattern of holes that is used for fixing seats and wheelchairs inside the minibus. There are different type of airline tracks that Tribus uses which all have different track gauges. Each type of airline rail therefore induces a different frame that is adapted to the suitable track gauge of this floor system.

The aforementioned reasons effectuate a large variety of frames which currently resulted in eight types of base frames and eleven types of wheel arch brackets. In Figure A.2 a selection of these frames are shown.

Tribus uses different kind of floor adapters to make the connection between the Flexus seats and the aluminium floor profiles. Despite the numerous commercially available floor adapters, one can divide the adapters in two categories.

The first category is the removable floor adapter, known as the lockable. The lockable is an adapter that is used to quickly remove the seat from, or reposition the seat in, the vehicle without the use of additional tools.

The second category is the fixed floor adapter, known as the t-bolt. The t-bolts are the
economic variant of the floor adapters and are used for seats that does not have the need to be removed or repositioned.

In Figure A.3 possible Flexus floor adapters are shown. The lockable shown in A.3a is a type of lockable that is able to unlock the seat by rotating the turning knob by a quarter of a turn. The seat can be lifted out of the airline track and moved to another location. The lockable in A.3b is operated by a turning knob with a screwing principle. The difference with respect to the lockable in A.3a is that repositioning of the (unlocked) seat is possible by sliding it through the airline track without the need of lifting the seat. In A.3c the t-bolts are shown that are used for permanent fixation of the seat frames to the airline track.

Figure A.3: Possible Flexus floor adapters

The transformation of the FlexusPRO tip seat from mode 1 to mode 2 is shown in Figure A.4. Starting in mode 1 (A.4a) the armrest is pulled upwards in the direction of the backrest. Subsequently a release pin is pulled to unlock the seat pan in order to ‘tip’ it to the backrest (A.4b). The red lever above the base frame of the seat is operated, which enables the rotation of the seat package (A.4c). Finally, rotation of the seat is possible until it automatically locks in its new position, mode 2 (A.4d).

Figure A.4: Transformation of the FlexusPRO tip seat from mode 1 to mode 2
The swivel, which is the device that allows the seat to rotate, is shown in Figure A.5. The rotation of the swivel is performed by ball bearings. Because of the overhanging seat frame, the constructor of the swivel decided to position two bearings above one another, in order to absorb the moment of force, exerted on the rotation device. In principle, this is a good solution. However, the drawback is that the swivel needs a certain height to store the bearings above each other in order to be effective. As already mentioned before, the extra height of the swivel is compensated by an extra base frame, to ensure similar seating heights for the *FlexusPRO* and the *FlexusPLUS* which is undesirable.

Besides the fact that the ball bearings effectuate a smooth rotation, they are relatively expensive and determine a major part of the assembled swivel costs. In appendix D the drawbacks of Tribus’ current swivel are further elaborated.

*Figure A.5:* The rotation device (swivel) for the *FlexusPRO*
Appendix B

List of design requirements

This appendix shows the list of design requirement for the new *FlexusPRO* seats. Each requirement is numbered and will be explained after Table B.1. A distinction has been made between the internal requirements, external requirements and preferences. The internal requirements indicate the demands determined by Tribus. External requirements are submitted by legislation or customers. Preferences are items that are not required but can make the difference between one concept and another.

Table B.1: List of design requirements

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Description</th>
<th>Intern</th>
<th>Extern</th>
<th>Preferred</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Minimum of 30% cost reduction;</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Minimum of 30% weight reduction;</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Minimum of 10% increase of lateral wheelchair space;</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Minimum of 20% increased view outside for the wheelchair occupant;</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Must meet EU directive 74/408/EEG;</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Must meet EU directive 76/115/EEG;</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Must meet EU directive 77/541/EEG;</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Maximal width of the seat is 450 mm;</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Maximal depth of the seat is 420 mm;</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Minimal depth and width of the seat is 400 mm;</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Reduction of seat components;</td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
Table B.1 – continued from previous page

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Description</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Construction of the vehicle should not be changed;</td>
<td>X</td>
</tr>
<tr>
<td>13</td>
<td>Seats are floor mounted;</td>
<td>X</td>
</tr>
<tr>
<td>14</td>
<td>Seats are compatible with track gauges of 95, 115 and 121 mm;</td>
<td>X</td>
</tr>
<tr>
<td>15</td>
<td>At least eight seats should fit in the vehicle;</td>
<td>X X</td>
</tr>
<tr>
<td>16</td>
<td>The maximal package size of the seat in mode 2 is 180 mm;</td>
<td>X X</td>
</tr>
<tr>
<td>17</td>
<td>The seat should have the possibility to be positioned on different lateral positions with respect to the base frame of the seat;</td>
<td>X X</td>
</tr>
<tr>
<td>18</td>
<td>The base frame of the seat is compatible with the current floor adapters for mounting the <em>Flexus</em> seats on the aluminium floor profiles;</td>
<td>X</td>
</tr>
<tr>
<td>19</td>
<td>The wheel arch brackets should have a capacity of two seats;</td>
<td>X</td>
</tr>
<tr>
<td>20</td>
<td>The seats positions on the wheel arch bracket should be variable;</td>
<td>X</td>
</tr>
<tr>
<td>21</td>
<td>Operation of seat mechanisms have to be performed mechanically;</td>
<td>X</td>
</tr>
<tr>
<td>22</td>
<td>Operations for transforming the seat from mode 1 to mode 2 and vice versa needs to be intuitive;</td>
<td>X</td>
</tr>
<tr>
<td>23</td>
<td>The amount of operations that are needed for transformation cannot increase with respect to the <em>FlexusPRO</em>;</td>
<td>X</td>
</tr>
<tr>
<td>24</td>
<td>The seat transformation is performed without (re)moving the seat;</td>
<td>X</td>
</tr>
<tr>
<td>25</td>
<td>The transformation between the two functional modes for eight seats has to be realized within 1 minute;</td>
<td>X</td>
</tr>
<tr>
<td>26</td>
<td>One type of transformation mechanism is used for seats on a base frame, as well as for seats on a wheel arch bracket;</td>
<td>X</td>
</tr>
<tr>
<td>27</td>
<td>Operation of the transformation mechanism has to be uniform;</td>
<td>X</td>
</tr>
<tr>
<td>28</td>
<td>Operation of the transformation mechanism has to be performed by normal body force;</td>
<td>X</td>
</tr>
<tr>
<td>29</td>
<td>The wheel arch bracket should have a similar appearance as the base frame of the seat;</td>
<td>X</td>
</tr>
<tr>
<td>30</td>
<td>The position of the upper point of the three point safety belt cannot be outside the seat structure;</td>
<td>X</td>
</tr>
<tr>
<td>31</td>
<td>The seating height is 460 mm;</td>
<td>X</td>
</tr>
<tr>
<td>32</td>
<td>The seat must provide an increased lumbar support with respect to the <em>FlexusPRO</em>;</td>
<td>X</td>
</tr>
</tbody>
</table>
Table B.1 – continued from previous page

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Description</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>The thickness of the backrest must be reduced to increase the possible seat positions in the vehicle (in longitudinal direction);</td>
<td>X</td>
</tr>
<tr>
<td>34</td>
<td>The seat must be distinctive with respect to its operation and appearance;</td>
<td>X</td>
</tr>
<tr>
<td>35</td>
<td>Reduce assembly time as much as possible;</td>
<td>X</td>
</tr>
<tr>
<td>36</td>
<td>The seat should have a minimal amount of play;</td>
<td>X</td>
</tr>
</tbody>
</table>

1. Due to the economic crisis, the costs for the conversion of a minibus becomes more and more important. A vehicle is equipped with eight seats that contribute to a substantial part (25%-30%) of the total costs of a converted vehicle. In order to compete with other vehicle converters and seat manufacturers, the production costs of the FlexusPRO seats has to be reduced with at least 30%.

2. The weight of the seat has a huge influence on many levels in the transportation sector. Weight reduction of the seat increases the boundary with respect to the critical restricted gross weight of a M1 vehicle. It will reduce fuel consumption and CO$_2$ emission and facilitates lifting of the seat. According to the National Institute of Occupational Safety and Health (NIOSH), the weight of the seat must be reduced by at least 30% to prevent any health damage when lifting the seat.

3. The current FlexusPRO seats in mode 2 are tilted to the inside of the vehicle, which means that a substantial part of the available lateral wheelchair space cannot be used. Because of this position in mode 2 the lateral space varies from 1330 mm to 1215 mm where the seat is tilted maximally to the inside of the vehicle. The competitor can realize a lateral wheelchair space of 1340 mm. In order to improve the lateral space and exceed the available wheelchair space of the competitor, the lateral space must be increased with at least 10% with respect to the most inner point of the seat in mode 2.

4. The FlexusPRO seats in mode 2 are currently covering more than 70% of the window area of the vehicle. The height of the seat is approximately similar to the eye level of the wheelchair occupant which means that the seats obstruct an unhindered view to the outside of the vehicle. Furthermore, the occupant experiences a sense of claustrophobia when all seats are transformed into mode 2 and hardly any view outside is possible. By reducing the height of the seat in mode 2, the covered window area must be reduced with at least 20% to improve the view outside and increase the comfort perception of the wheelchair occupant.

5. By regulation

6. By regulation

7. By regulation
8. The literature study that has been done prior to this thesis showed that the width of the seat is restricted to 450 mm in order to realize the best seating comfort considering the minimal restricted aisle width when three seats are positioned side by side.

9. The literature study that has been done prior to this thesis showed that the depth of the seat is restricted to 420 mm in order to realize the best seating comfort in combination with the accessibility of the seat when the seats are positioned behind each other.

10. By regulation

11. The *Flexus* seats have a large variety of components which causes unfavourable procurement logistics and require a large amount of stock area. Less seat components will reduce the necessary stock area and the overall costs for the seats.

12. As explained earlier, a cost reduction is a very important requirement. This means that an improvement must be found in the seat only, instead of the combination with a modification of the vehicle. This will increase the amount of work that is needed for the conversion which will negatively influence the turnaround.

13. The seats need to be floor mounted because at least 95% of the minibuses for combined transportation is equipped with floor mounted seats. A different fixation between the vehicle and the seat would prevent marketing of the seat to other companies.

14. Tribus offer the customer three types of aluminium floor profiles which all have a different track gauge. The seat must be able to fit all three track gauges without any additional seat components.

15. According to M1 regulations one is allowed to transport eight people which means that it must be possible to fit eight seats in the vehicle.

16. The lateral wheelchair space to the rear of the vehicle is restricted by the wheel arches of the minibus. To prevent that the seat in mode 2 is causing a decrease in available wheelchair area, it cannot exceed the width of the wheel arches and is therefore restricted to 180 mm.

17. The possibility of positioning the seat in multiple lateral positions with respect to the base frame of the seat is providing the customer with an increased seating flexibility. The seats can be positioned close to the side of the vehicle to increase the aisle width, or one can choose to increase the space between the side of the vehicle and the seat in order to improve the seating comfort for the passenger.

18. The compatibility of the base frame of the seat with the current floor adapters makes the seat interesting for other companies that have other aluminium floor profiles.

19. Dependent on the length of the vehicle that needs to be converted, it is sometimes necessary to position two seats above the wheel arches in order to be able to fit eight seats in a vehicle.

20. Tribus’ current wheel arch bracket has fixed seat positions. The seat positions are determined by the seating plan and the length of the vehicle. This results in a variety of wheel arch
brackets which can be reduced to one bracket if the seats can be (re)positioned at multiple locations on the bracket. This will reduce the required stock area tremendously.

21. Because the seats can be (re)positioned anywhere in the vehicle, an electrically operated mechanism requires a battery. This will have a negative influence on the weight of the seat and it will be more susceptible to malfunction.

22. Many clients have a variety of drivers for their vehicles that mostly don’t read the instruction manual of the seat. If the operations are intuitive a user instruction is hardly necessary.

23. Most transportation companies are time driven which means that many operations for the transformation will not be well received by the drivers and if possible be omitted. A quick and easy transformation is therefore necessary.

24. As already discussed, the seats can be positioned anywhere in the vehicle which makes the vehicle multifunctional when additional space is needed for e.g. large wheelchairs. However, this repositioning of the seat cannot be the solution to create the ‘normal’ wheelchair space because it requires extra attention from the driver to replace the seat in the correct position when the seat is used for ambulant passengers. Furthermore, the time required for the transformation will probably increase and for vehicles where a total of six wheelchairs will have to be transported at once, the size of the minibus is not sufficient to store the seats at a different position.

25. Time is an important factor for commercial transportation companies. A time efficient transformation has its influence on the amount of passengers that can be transported. The transformation of eight FlexusPRO seats is realized within one minute which cannot be exceeded by the new seat.

26. As discussed in section 1.2.2 a reduction of components will benefit the procurement logistics and reduce costs. A uniform transformation mechanism for both seat and base frame is therefore required.

27. The release mechanism of the swivel of the FlexusPRO is operated by a hand lever. However, because the swivel is used on both the right and the left side of the seat the rotation device is release by pushing or pulling this lever. This can be confusing for the operator and therefore a uniform operation is desired.

28. The operators of the new seat will have to be able to release the rotation device without using excessive force. It is therefore required that the transformation mechanism is operated by normal body force.

29. For a uniform and calm appearance in the vehicle it is desired that both base frame and wheel arch bracket have a similar look.

30. The upper point of the three point safety belt of the FlexusPRO is currently positioned outside the structure of the seat and is situated at a location close to the window when the seat is positioned maximally to the side of the vehicle. However, this means that the seat
cannot be positioned near the C pillar of the vehicle because of the interference with the cover for the upper point of the safety belt. When the upper point of the belt lies within the boundaries of the seat structure, the seat can be positioned anywhere along the available (longitudinal) space of the minibus.

31. The literature study that has been done prior to this thesis showed that the height of the seat is determined to 460 mm in order to realize the best seating comfort considering the popliteal height of the Dutch adults between 20 and 60 years of age and adults of 60 plus years of age.

32. The FlexusPRO doesn’t have a lot of lateral lumbar support which can be noticed when a driver takes turns. An increased lumbar support will improve a steady seating position during driving which will improve the comfort perception of the passenger.

33. The minimal distance between two seats in longitudinal direction is imposed by the Government [7] and showed in Figure B.1. The length of the vehicle in combination with the thickness of the backrest determines the positions of the seats in longitudinal direction. A reduction of the thickness of the backrest will increase the possible seat positions and therefore the multifunctionality of the minibus.

34. Tribus wants to distinct itself from its competitors by introducing their improved seat. A different operation and appearance will only consolidate this.

35. If the time, needed to assemble a complete seat, is reduced as much as possible, the additional time that is saved can be used for other work which will increase the productivity of the employee.
36. No excessive play is allowed when the seat is transformed into one of the functional modes. For example, if the swivel shows a certain play in one or both modes, the entire seat will show an even higher rate of play, which results in vibrations that causes unfavourable noise during driving.
Appendix C

Tilting principle

This appendix shows the relation of the joints of the backrest with respect to the seat pan to ensure an over-centre position in functional mode 1 and a simultaneous movement of these seat components to reach functional mode 2.
Figure C.1: Pivot point positions
Figure C.2: Side view, isometric view and detailed view of the prototype tip seat in over-centre state

Figure C.3: Side view, isometric view and detailed view of the prototype tip seat in dead centre state
Figure C.4: Side view, isometric view and detailed view of the prototype tip seat in unclamped state
Appendix D

Swivel

In this appendix, the drawbacks of the current swivel are elaborated per item. The drawbacks have influence on Tribus, the customer and the passengers which will become clear in the next sections.

D.1 Weight

One of the biggest drawbacks of the swivel is its weight. The current weight of the swivel is 4.8 kg, which is 15% of the entire seat weight. As already discussed in section 1.2.1 the weight of the seat has to be reduced to realize a larger gap between the actual gross weight of the converted minibus and the maximum allowed gross weight for M1 vehicles. Furthermore a weight reduction will improve the labour conditions with respect to lifting the seat and reduce the fuel consumption and CO\textsubscript{2} emission which is good for both customer and environment.

D.2 Stiffness discrepancy

The construction of the swivel is not entirely symmetrical. The designer of the swivel decided to apply a pin-slot combination in order to fix the seat in different rotational positions as can be seen in Figure D.1. The benefit of this system is that the pin is enclosed by the slot which prevents unlocking as a result of an impact. However, the slot weakens the construction which has an influence on the weight and the stiffness of the swivel.

The FlexusPRO is always used for multifunctional transportation purposes. This means that the seats are always positioned maximally to the left or right side of the vehicle in order to realize a maximal wheelchair space when the seats are transformed to mode 2. It also means that the swivel is always positioned on the left or right side of the seat frame resulting in a overhanging seat with respect to the base frame. Because the seat has two different positions (mode 1 and mode 2) with respect to the slot of the swivel (Figure D.1), the forces on the swivel due to the weight of the seat causes different reactions on the swivel.

When the seat is transformed into mode 1, the weight of the seat causes a moment of force around the longitudinal axis of the swivel. Along this axis, the swivel is relatively stiff because the slot is only positioned on top (referred to Figure D.1). The moment of force around
APPENDIX D. SWIVEL

Figure D.1: Stiffness discrepancy of Tribus’ current swivel, where the dotted line indicates the seat frame. (The picture is shown from the bottom)

the longitudinal axis of the swivel will be mainly absorbed by the bottom part (referred to Figure D.1) of the swivel where there is full material.

However, if the seat is transformed into mode 2, the weight of the seat causes a moment of force around the lateral axis of the swivel. Along this axis, the swivel is relatively weak because the slot is mostly positioned in this lateral plane. The moment around the lateral axis will be absorbed by the left and right part of the swivel (referred to Figure D.1) where hardly any material is left. Because of this stiffness discrepancy, the seat in mode 2 (without a passenger) starts to resonate during driving which causes an annoying rattling sound for both the driver as the passengers.

D.3 Operation

To reduce components, Tribus decided to use only one swivel for both left and right side. However, the drawback of this swivel is the operation of the release mechanism. The pin, that is preventing the swivel from rotating is operated by a lever. Dependent on which side of the seat frame the swivel is mounted, the pin can be moved out of its fixed position in the slot, by pushing or pulling the (red) lever (Figure D.1). One can imagine that this is confusing for the operator.

Besides its variable operation, the lever is also positioned under the seat frame which is shown in Figure D.2. Considering the fact that inside the vehicle the release mechanism can only be reached from the side of the seat, because of the other surrounding seats, the lever is difficult to see and relatively hard to reach.
D.4 Assembly

Finally, the assembly of the swivel to the seat frame as well as to the base frame is not optimal due to technical design flaws. The accessibility of the nuts for fixing, or removing, the swivel to, or from, the seat frame is not favourable because it can only be reached when the seat pan is removed from the seat. Another drawback is the fact that not all the bolts in the swivel can be restrained by a tool which might cause it to start rotating when the nuts are tightened. This sometimes increases the assembly time.
Appendix E

Morphological schemes

This Appendix shows the results of the morphological analysis for the entire tip seat (E.1) as well as for the rotation device (E.2).

E.1 Tip seat concepts

Figure E.1 shows the resulting concepts for the entire tip seat based on the scheme in Figure E.2. Each concept is rated in accordance with the list of design requirements. A distinction has been made between manufacturing aspects and usage aspects of the seat. In table E.1 the ratings for these aspects are shown where each number in column Requirements refers to the item number in the list of design requirements of Appendix B.

(a) Concept A  
(b) Concept B  
(c) Concept C

Figure E.1: Resulting morphological tip seat concepts A, B and C
APPENDIX E. MORPHOLOGICAL SCHEMES

Usage

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Concept A</th>
<th>Concept B</th>
<th>Concept C</th>
<th>Ideal concept</th>
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<tbody>
<tr>
<td>2 Weight</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>4</td>
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<tr>
<td>3 Wheelchair space</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>4 View outside</td>
<td>3</td>
<td>4</td>
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<td>4</td>
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<td>23 Operations</td>
<td>3</td>
<td>3</td>
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<td>4</td>
</tr>
<tr>
<td>33 Longitudinal positioning</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Total x</td>
<td>15</td>
<td>16</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td>Total % x</td>
<td>75%</td>
<td>80%</td>
<td>65%</td>
<td>100%</td>
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Manufacturing

<table>
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<th>Concept B</th>
<th>Concept C</th>
<th>Ideal concept</th>
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<tr>
<td>1 Costs</td>
<td>3</td>
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<td>1</td>
<td>4</td>
</tr>
<tr>
<td>2 Weight</td>
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<td>3</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>34 Distinctive</td>
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<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Total y</td>
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<td>7</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>Total % y</td>
<td>75%</td>
<td>58,3%</td>
<td>58,3%</td>
<td>100%</td>
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</table>

Table E.1: Ratings for the tip seat concepts with respect to Usage (x) and Manufacturing (y)

The ratings per concept are substantiated below.

1 Costs
The movable backrest of concepts A and B results in increasing costs for extra fixation. Concept C also affects the floor of the vehicle which will increase the costs.

2 Weight
The separate headrest for all concepts is not beneficial for the overall weight of the seat because of additional mechanisms that are needed to lock the headrest. For concept C an additional fixation mechanism is needed to fix the seat on the vehicle floor.

3 Wheelchair space
Both concept A and B could provide similar space in lateral direction, but because of the package height with respect to the floor, concept B is rated higher. Concept C is completely moved within the vehicle floor, which results in the maximal available width.

4 View outside
Concept A shows an improvement of view outside for the wheelchair occupant, but a part of the seat remains in front of the window. Neither concepts B nor concept C hinder any view outside of the wheelchair occupant.

23 Operations
The amount of seat parts movements of concept A is increased with respect to the FlexusPRO. However combination of movements might reduce the amount of operations needed, which also applies for concept B. As for concept C, the complete seat package needs to be moved within the vehicle floor which results in extra operations.
33 Longitudinal positioning  An increase of possible seat positions in longitudinal direction of the vehicle depends on the thickness of the backrest, but also on the size of the seat package in mode 2 of the tip seat. Concepts B and C both require additional space in longitudinal direction. Moreover, concept C moves completely within the vehicle floor which limits the possible seat positions.

34 Distinctive  Because of the separate headrest and the movable backrest, concept A is different with respect to the FlexusPRO and competitor seats. Concept B is similar with the tip seat of Tribus’ main competitor where concept C is completely new within the wheelchair transportation sector.
Figure E.2: Morphological scheme of the tip seat concepts
E.2 Swivel concepts

Figure E.3 shows the resulting concepts for the new swivel based on the morphological scheme of the swivel in Figure E.4 on page 66. Each concept is rated in accordance with the list of design requirements. For this rating only the manufacturing aspects are taken into account, because in principle the use of these concepts are similar and would result in equal ratings. The ratings for the manufacturing aspects are shown in table E.2, where each number in column Requirements refers to the item number in the list of design requirements of Appendix B.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Concepts</th>
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<tbody>
<tr>
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</tr>
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<td>2 Weight</td>
<td>4</td>
</tr>
<tr>
<td>11 Reduction of components</td>
<td>4</td>
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<tr>
<td>17 Different seat positions</td>
<td>3</td>
</tr>
<tr>
<td>35 Reduction of assembly time</td>
<td>3</td>
</tr>
<tr>
<td>36 Amount of play</td>
<td>3</td>
</tr>
<tr>
<td>Total y</td>
<td>18</td>
</tr>
<tr>
<td>Total % y</td>
<td>75%</td>
</tr>
</tbody>
</table>

Table E.2: Ratings for the swivel concepts with respect to Manufacturing (y)

1 Costs Concept 1 is a component that needs to be machined by use of a turning lathe and milling machine. The bearing principle however needs hardening of the material which increases the costs. Tribus was not able to find a company that could provide such a turntable bearing below or around the cost price of €57,- of the current swivel, which is why it has the lowest rating. Concept 2 is a combination of forged aluminium with lathing and milling operations for the critical parts only. The assembly of the swivel is very easy and a complete swivel can be produced under the cost price of the current swivel. Concept 3 is a steel swivel that needs lathing and milling operations for the critical parts only. The other parts could be relatively low cost laser cut or punched parts. Concept 4 is a swivel that mainly exists of sheet metal parts. These laser cut parts are relatively low cost and production tools (punching) can be made to reduce the production costs even more. The time to assemble it will determine a major part of the cost price.

2 Weight All four concepts are designed to reduce weight as much as possible. Because none of the concepts are fully elaborated, the precise weight cannot be determined yet. However, major changes are not to be expected which means that the weight for all concepts will remain below the 3 kg which is a reduction of 38%. That’s why all concepts have the highest possible rating.
APPENDIX E. MORPHOLOGICAL SCHEMES

11 Reduction of components
One of the requirements is to reduce seat components in order to improve the procurement logistics. The rating is based on the amount of different parts that are used for the swivel assembly. The height of the swivel currently resulted in different base frames to compensate the seating height for fixed and tip seats. However, the swivel height is not taken into account, because the swivel can be integrated into the base or seat frame in order to have similar seating heights for both Flexus seats without the need of additional base frames.

17 Different seat positions
The seat should have the possibility to be positioned on different lateral positions with respect to the base frame of the seat. This means that multiple fixation points (in lateral direction) on the seat frame are needed to attach the swivel to the frame. However, additional holes or slots will weaken the seat frame, which could have a negative influence on the loads that it has to withstand. That’s why the rating is based on the amount of fixation holes in the swivel that are needed to fix it to the seat frame.

35 Reduction of assembly time
A reduction of assembly time can be based on the swivel component itself, but also on the time that is required to fix the swivel to the base frame and the seat frame. The ratings for this requirement is therefore based on the amount of component parts and the amount of holes that are used for fixing the swivel to the base and seat frame.

36 Amount of play
The amount of play is based on the amount of parts that influences this play. Because the parts of the swivel component for all concepts are not connected with a press fit, there will always be a certain amount of play in order to be able to rotate the seat. This is why the highest rating for the concepts is 3 instead of 4.

One can see that the ratings for concepts 1, 2 and 4 do not differ that much from one another. However, concept 3 received the highest rating. This concept is easy to assemble, it’s relatively cheap and the amount of play can be determined by the tolerances on the thickness of the inner and outer ring. Concept 3 will be further elaborated.
Figure E.3: Morphological concepts 1, 2, 3 and 4
Figure E.4: Morphological scheme of the swivel for the tip seat
Appendix F

Swivel drawings

This appendix shows the drawings of the new swivel components that are designed for this project based on the main criteria which are a reduction of cost price and weight.
Figure F.1: Swivel bottom
Figure F.2: Swivel top
Figure F.3: Swivel bottom support
Figure F.4: Locking strip
Figure F.5: Locking disc
Figure F.6: Swivel assembly

<table>
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<th>Item no.</th>
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<th>Aantal</th>
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<td>Swivel bottom</td>
<td>002</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Swivel top</td>
<td>003</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Locking strip</td>
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</tr>
<tr>
<td>4</td>
<td>Locking disc</td>
<td>006</td>
<td>1</td>
</tr>
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<td>5</td>
<td>Swivel bottom support</td>
<td>004</td>
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<td>6</td>
<td>Counterturn ball M6x12</td>
<td>DR27915</td>
<td>2</td>
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---

Swivel assembly
Figure F.7: Three assembly stages of the physical prototype of the swivel assembly

Figure F.8: Physical components of the swivel assembly
Appendix G

Headrests

This appendix illustrates current headrests of commercial vehicles to show their variety in appearance and operation. Table G.1 shows the dimensions of the headrests from the different vehicle types in Figure G.1 and their corresponding adjustable height. One can see that headrest height adjustments of current vehicles can be realized up to 210 mm. This means that in theory, the height of the new Flexus seats can be reduced by 210 mm by applying a separate headrest. This will benefit the view outside for the wheelchair occupant.

<table>
<thead>
<tr>
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<th>Thickness</th>
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<tr>
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<tr>
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<tr>
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<td>160</td>
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<td>240</td>
<td>120</td>
<td>45</td>
<td>130</td>
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</tbody>
</table>

Table G.1: Dimensions of headrests from different vehicle types in mm referred to Figure G.1. (Note that the pictures of the Volvo V70 and the Volvo S40 are not shown.)

Figure G.1: Headrest solutions of commercial vehicles

Figure G.2 shows a variety of car seats where the focus lies on the appearance and operation of the headrests which is used as inspiration for the headrest solution of the new Flexus seats.
Figure G.2: Commercial car seats focusing on the appearance and operation of the headrests
Appendix H

Calculations

In this chapter, the horizontal and vertical components of the loads on the three point safety belt are calculated. The locations of the anchor points are shown in Figure H.1. The variables are shown below.

\[
\begin{align*}
F_1 &= 13700 \text{ N} \\
F_2 &= 13700 \text{ N} \\
g &= 9.81 \text{ m/s}^2 \\
\alpha &= 10 \text{ degrees} \\
m_{\text{seat}} &= 30 \text{ kg} \\
x_1 &= -30 \text{ mm} \\
x_2 &= -110 \text{ mm} \\
y_1 &= 75 \text{ mm} \\
y_2 &= 795 \text{ mm} \\
z_1 &= 145 \text{ mm}
\end{align*}
\]

The load on the diagonal belt is applied in the middle of the bottom and top anchor point which is \(x_1 + \frac{x_2 - x_1}{2} = 70 \text{ mm}\) in x-direction from the origin and \(y_1 + \frac{y_2 - y_1}{2} = 435 \text{ mm}\) from the origin in y-direction. The loads on the hip belt are applied on the bottom anchor points which are positioned 30 mm from the origin in x-direction and 75 mm from the origin in y-direction. Both loads are applied 145 mm from the origin in z-direction.

\[
\begin{align*}
F_{1h} &= F_1 \cdot \cos \alpha \\
F_{1v} &= F_1 \cdot \sin \alpha \\
F_{2h} &= F_2 \cdot \cos \alpha \\
F_{2v} &= F_2 \cdot \sin \alpha \\
F_{\text{seat}} &= 20 \cdot m_{\text{seat}} \cdot g
\end{align*}
\]
Figure H.1: Locations of the anchor points of the safety belt with respect to the bottom center part of the swivel assembly.
Appendix I

FEM analysis

This appendix shows the results of the FEM analysis of the swivel assembly, that is performed with the help of SolidWorks Simulation software. The goal of the analysis is to check the strength of the rotation device and the restraint of the rotation, regarding the Locking strips, shown in Figure F.4 on page 71. This means that, referring to Figure F.6 on page 73, only the components Swivel top, Swivel bottom and the two locking strips are analysed. For this FEM analysis, certain assumptions are made to facilitate the calculation of the swivel assembly.

Because the (new) top part of the seat (everything above the swivel assembly) is not known, this part is assumed to be infinitely stiff, which will guide the forces, applied on this structure (three point safety belt), directly to the swivel assembly. This so called external load is applied on the bolt holes of component Swivel top. The EU Directive 76/115/EEG [3], prescribes a load on the diagonal belt of 13.7 kN in an upward angle of 10 degrees with respect to the horizontal plane. The loads on the hip belt is 13.7 kN in the same direction, but in combination with a load that is 20 times the weight of the seat. This weight is assumed to be 30 kg, in order to be on the safe side, considering the weight reduction that is expected for the new tip seat. The loads in x- and y-direction are shown in Figure I.1.

The base of the seat, which is the support for the swivel assembly, is also assumed to be infinitely stiff, meaning that possible deformations of the swivel parts are not allowed to move in the direction of the base frame. This support surface (the top part of the base frame) of the swivel assembly is simulated with a so called virtual wall, which is shown in Figure I.2.

The Swivel bottom (Figure F.6 on page 73) is bolted to the base frame of the seat and therefore the bolt holes in this component are fixed. The Locking strips are fixed in a way that they are not able to move to each other. The fixtures are shown in Figure I.3.

Finally, the relations between the contact surfaces are defined in order to prevent penetration of the parts.
Figure I.1: Applied external load on *Swivel top*

Figure I.2: Applied virtual wall to simulate the support surface of the base frame of the seat.
Figure I.3: Applied fixtures on the swivel components
Figure I.4: Stress plot of the swivel assembly with the applied loads and their direction shown. The deformation scale is 92
**Figure I.5:** Detailed stress plot of the swivel assembly. The deformation scale is 92

**Figure I.6:** Detailed stress plot of the swivel assembly. The deformation scale is 1
**Figure I.7:** Detailed stress plot of the swivel assembly for stresses above 355 N/mm². Element volume is 11.64%.

**Figure I.8:** Detailed stress plot of the swivel assembly for stresses above 510 N/mm². Element volume is 5.80%.
Figure I.9: Detailed stress plot of the swivel assembly for stresses above 680 N/mm$^2$. Element volume is 2.87%

Figure I.10: Displacement of the swivel assembly. The deformation scale is 92
Appendix J

Physical pull test

In this appendix, the photos of the swivel after a physical pull test are shown. In Figure J.1 the graph of the force, exerted by the two pull cylinders, on the three point belt assembly of the seat, are shown.

Figure J.1: Graph of the exerted force, in Newtons, of the two cylinders on the three point belt and lap belt respectively
Figure J.2: Right side of the seat after the physical pull test in accordance with directive 76/115/EEG

Figure J.3: Left side of the seat after the physical pull test in accordance with directive 76/115/EEG
Figure J.4: Left side of the swivel after the physical pull test in accordance with directive 76/115/EEG

Figure J.5: Front side of the swivel after the physical pull test in accordance with directive 76/115/EEG
Figure J.6: Rear side of the swivel after the physical pull test in accordance with directive 76/115/EEG
Bibliography

Literature


