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# Wheelchair Modification

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The University of Akron
College of Engineering

Biomedical Engineering Senior Design Project
Team 14 Final Report

The University of Akron

# Wheelchair Modification
EnGenious Design Solutions

Stephen Conklin, Kenneth Hutson, Nolyn Martz, William Rasper, Taylor Verba

April 29, 2019

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## ABBREVIATIONS

| | |
|---|---|
| EnGenious Design Solutions | EDS |
| God's Hidden Treasures | GHT |
| Design History File | DHF |
| Functionality Analysis | FA |
| International Organization for Standardization | ISO |

## ABSTRACT

This document outlines the design process for a wheelchair modification. This wheelchair modification is the Senior Capstone Project for five undergraduate students studying Biomedical Engineering at The University of Akron, Team 14. The team was directed to compose a team name, which was chosen to be EnGenious Design Solutions (EDS). The project was provided by Dr. James Keszenheimer who is a professor at The University of Akron. This document focuses on the project results as well as business conclusions.

## DESCRIPTION OF PROJECT PROBLEM

Transportation of children with special needs in Ukraine is a serious and unaddressed problem that the country faces. Current wheelchairs lack the simplicity and ease of use that caregivers desire from a wheelchair as well as numerous functional drawbacks.

There are varying issues with the current wheelchairs that are being used. These issues include wheels that don't pivot (making turning difficult), wheelchairs that do not have breaks, wheelchairs that are too heavy to be lifted up, wheelchairs with the inability to fold up and be transported, wheelchairs lacking proper and comfortable seat belts, wheelchairs with padding that cannot be removed for washing purposes, and wheelchair issues with comfort. A current wheelchair that is used in Ukraine can be seen below in Appendix A Figure 1.

The goal of this project is to design and fabricate a wheelchair prototype that meets the requirements given by the client and created by the team. The prototype, drawings, and all relevant Design Control documentation will be sent to God's Hidden Treasures in order to be manufactured in the Ukraine.

Most of the wheelchairs offered to users in the Ukraine fall under two industry categories: the manual chair, and the transport chair. The manual wheelchair has larger wheels and is meant to be self-propelled, which is an impossible task for the current user population. However, this class of wheelchair is also designed with more comfort and durability, as it is intended to be used for most of the day. The transport wheelchairs are lighter than manual wheelchairs, as they are normally made out of lighter materials. They are highly foldable and considered easier to use on the part of user, as patients using these chairs normally do not self-propel. This type of wheelchair is more common in the Ukraine, due to its lighter weight and foldability.

The patients that will be utilizing the EDS product have a variety of disabilities that severely affect their ability to walk or transport themselves. These disabilities include paralysis, cerebral palsy, and other diseases that affect the motor skills of an individual. The wheelchair that is most used by the caregivers of cerebral palsy patients is a stroller derivative of the transport wheelchair. Given the needs of the client, both classes of wheelchairs are important factors in the new design. The EDS design combined the foldability and light weight of a transport wheelchair with the durability and increased comfort of a manual wheelchair. However, the final

prototype resembled more of a transport wheelchair than a manual wheelchair.

Some of the novel features of this design include that the wheelchair is a hybrid between a typical lightweight transport wheelchair, and an everyday manual wheelchair. To accomplish this, the frame was kept lightweight, but extra padding was added. Additionally, the wheelchair folds in a Z-fold pattern similar to a lawn chair which allows for the structure of the frame to remain intact and not compromise the design with stress risers. The EDS team designed a folding mechanism that is able to accommodate the thickness of extra padding. When folded, the wheelchair will be similar to a dolly, allowing easier transportation via stairs.

## BACKGROUND

The team was contacted by Scott Yount and Nita Hanson from God's Hidden Treasures (GHT) as well as Claudine Schooley who is now a part of The Akron Rotary Club. God's Hidden Treasures is an organization that provides ministry to those in need. The wheelchair ministry section of GHT is working with EDS on this wheelchair modification. The wheelchair ministry has been providing wheelchairs, walkers, canes, and other mobility aids to the people of Ukraine for over 15 years (God's Hidden Treasures, 2018). God's Hidden Treasures reached out to EDS because although the Ukraine government is required by law to provide mobility aids to its people, the reality is that they never really have enough, the chairs are not available, or the chairs are not in any way fitted/suited for the user's needs (God's Hidden Treasures, 2018).

The patients that will be utilizing the EDS product have a variety of disabilities that severely affect their ability to walk or transport themselves. These disabilities have been identified to the team from the client as paralysis, cerebral palsy, and other diseases that affect the motor skills of an individual. The majority of these illnesses prevent the patient from being able to self-propel, so the assistance of another individual will be required. The ages for the patients utilizing this product range from 5 to 35 years old with the primary demographic being adolescent children. To accommodate the age range, the total weight capacity of the wheelchair modification is 250 lbs. (113 kg).

The wheelchairs that have been previously donated are disliked by the caregivers. Some of the feedback included lack of padding, stability, portability, cleanability, and folding capability. The need for the improved wheelchairs is due to the current living conditions for the caregivers and children living in Ukraine, where a single caregiver is responsible for the care of the disabled children. This places a focus on the ability of the wheelchair modification to be easily used by a caregiver in the transportation of their child. Along with single caregivers taking care of the children, the families usually live in tall buildings. These buildings can be seven stories tall or greater, with non-functioning elevators. With this condition, the necessity for the wheelchair to be able to be easily handled and traverse over varying terrain is important. Finally, the cultural environment in Ukraine stigmatizes people with disabilities. As a result of this, the country is not easily handicap accessible leaving caregivers with limited options for transportation.

## DESIGN REQUIREMENTS

In order to fully understand the design requirements for this wheelchair modification, the EDS team met with the client numerous times. As mentioned above, there were various points of contact for this design project. These contacts were all utilized in order to understand the user needs and wants for this design project. Two interviews were conducted by the EDS team, one with Scott Yount and another with Nita Hanson and Claudine Schooley. Interview notes were recorded and placed into the EDS team Design History File (DHF) in document number 205.00.

The main purpose of the interviews was to help the EDS team understand the “needs” vs. the “nice to haves” of the expected project deliverables. Once the interviews were complete, the EDS team sat down to understand the importance of all the objectives the client had mentioned during the meetings. The breakdown of importance can be seen in Appendix B Table 1.

Based on the interview notes and referenced table, a list of requirements was created by the EDS team. These requirements were stored in the EDS Design History File in document number 206.00. The main requirements that were the focus of the EDS team included the ones provided by Scott Yount as the “needs” for the wheelchair modification. Scott had mentioned that these six objectives were needed for the success of this project. The requirements were broken down into main categories that can be shown in Appendix C.

Once the requirements were finalized, the EDS team created specifications for the wheelchair modification project. The specifications were stored in the EDS Design History File in document number 402.00. These specifications provided numerical values that were then used as the acceptance criteria values during verification testing. The requirements and specifications are traceable to the verification matrix which was utilized for verification testing. The specification template was broken down into varying sections in order to provide accurate and efficient presentation.

## TESTING

In order to verify the requirements, the values documented in the specification template were translated into a verification matrix that is shown in Appendix E. This matrix was used for verification testing. The matrix was stored in the EDS Design History File in document 202.00. A test plan was created by the EDS team in order to facilitate the verification of numerous requirements. This test plan was stored in the EDS Design History File in document number 202C. The test plan explains the six phases of testing, of which only the first three were carried out by EDS due to time and constraints and lack of proper facilities and equipment to carry out specific tests. Protocols and results were formed for each testing phase as well as documented in the verification matrix. The protocols and results were stored in the EDS Design History File. Test phase explanations are provided in Appendix D.

All of the requirements passed the given acceptance criteria provided by the verification matrix as shown in Appendix E.

## BUSINESS ASPECT

Full research provided by GHT as well as EDS regarding the business aspects of this project were stored in the EDS Design History File in document 903.00. Based on the statistics found in this research, approximately 900,000 people need wheelchairs in Ukraine. Of these 900,000 people, about 135,000 are children under the age of 14 that require wheelchairs (Wheelchair Foundation, 2018-2019). To continue to represent the need for chairs in Ukraine, of the 135,000 children, only 13,500 have access to a wheelchair as shown in Appendix F Figure 1. This leaves 122,500 children from the age 0-14 that should require a wheelchair but do not have one. Given that the main wheelchair user population are children, this statistic is crucial to the wheelchair modification deliverable. The statistic of 122,500 children in need of wheelchair, is only reflects the needs of the Ukraine, and does not consider surrounding countries such as Romania, Moldova, and Belarus which are also in serious need (Wheelchair Foundation, 2018-2019). Appendix F Figure 1 shows the need for wheelchairs versus those who have access to wheelchairs in Ukraine.

Current products offered in the Ukraine market vary, as most items are donations from outside bodies, such as the organization Joni & Friends. These donated items are hard to assess as a whole, however thanks to God's Hidden Treasures, user needs were able to be interpreted in a quick and efficient manner by means of surveys found in Appendix F Table 1.

Since there is such a large need for wheelchairs in Ukraine, and the data shows that the current wheelchair solutions are not adequate, GHT estimates that they will be able to sell 1000 wheelchairs in the first year, but eventually sell enough chairs to meet the need completely. With the wheelchairs lasting a minimum of 10 years, approximately 4,000 wheelchairs would need to be sold per year. Figure 2 in Appendix F shows the projected financial statistics in terms of US dollars of merchandise sold per year.

## FINAL IMPLEMENTATION

The EDS team followed the design process highlighted in the provided textbook, *Engineering Design Process* (Haik, Sivaloganathan, & Shahin, 2018). In order to understand the functional components that would be implemented into the design, a functional chart was made. An initial chart was made before modeling began but was later updated to accurately represent the final wheelchair modification. This functional chart can be seen in Appendix G. Necessary calculations including pressure distributions and geometrical model dimensions were recorded in document 704.00 Analytical Methods which was stored in the EDS Design History File. The overall block diagram for this project is provided in Appendix H. It is important to note that this block diagram simulates a black box model with inputs and outputs. In other words, the processes that connect the inputs and outputs were not described in the block diagram. The final 3D wheelchair modification created by the EDS team can be found in Appendix I Figure 1. The photos shown in this appendix provide a clear picture as to the functionality of the hinge design in the folding of the wheelchair. The hinge was the most intricate assembly of the wheelchair modification which can be seen in Appendix I Figure 2. The fabrication of the hinge involved a lathe and mill for the most part. However, due to discussion with a welding specialist, it was decided that the end caps of the hinge needed to be created with a CNC machine. The original fabrication plans involved creating the components with a mill and lathe and then welding the components together. Through conversations with the welding specialist, it was decided that the end cap components would be fabricated with a CNC machine as the welding would actually melt the material to the extent of risking material strength. This part of the fabrication process may need to be revised in future manufacturing.

## DELIVERABLES

For this specific project, designs, drawings, and a wheelchair prototype were generated as part of the class requirements. The prototype was delivered to the client at the end of the project as well as testing results and drawings for future manufacturing. The project sponsor, Dr. James Keszenheimer, provided the EDS team with a schedule of deliverables over the 30-week time period. This deliverable schedule was stored in the team's DHF. The appendices provided in this report as well as other referenced documents were based on the deliverable schedule. A physical product was not one of the required deliverables for the senior capstone project, but the EDS team provided functional physical components to the client.

## SCOPE OF WORK EXCLUDED

EnGenious Design Solutions provided functional physical components. All testing that was not completed by EDS will be completed by manufacturers in Ukraine including reliability testing,

robustness of design and other tests as shown in Appendix E. Any further modifications or add-ons to the chair will not be designed or produced by EDS.

## PERFORMANCE STRESS RESULTS

Based on the verification matrix that is included in Appendix E, only a few stress tests were completed by the EDS team. The stress analyses were completed using finite element analysis via ANSYS Workbench 17.2. As a result of timeline and available resources, stress testing was not completed on a physical model. This has been outlined in the scope of work that was excluded in this project. The main stress tests involved verification for requirement numbers 19, 32, and 34 as shown in the verification matrix. Protocols were outlined for the stress tests.

It should be noted that during the functionality analysis testing, the first version of documents 805.30 and 806.30 provided results that did not meet the designated acceptance criteria for requirements 19 and 34. The results are documented in 806.30 and 806.30_V2 FA reports, but can also be seen in Appendix J.

In Appendix J Figure 1, it can be seen that when the 300 lb. load was distributed among 5 chair locations, the maximum stress was exhibited in the pin of the wheelchair modification. The pin material for the design was 18-8 Stainless Steel which has a yield stress of $2.15 \times 10^2$ MPa (NCEES, 2013). Therefore, the maximum experienced stress was greater than the yield stress, resulting in failure of acceptance criteria.

Based on the results of this verification testing, the EDS team decided to use a stronger material for the pin in the wheelchair modification. The finite element analysis was performed again with the new pin material in protocol 805.30_V2 and the results documented in 806.30_V2 FA Results. Figure 2 in Appendix J shows the maximum stress exhibited in the pin. The material of 1144 carbon steel was chosen. This material has a yield strength of $6.28 \times 10^2$ MPa (Eagle Steel, 2019) which is larger than the previous material. Based on these material properties, the finite element analysis results met the acceptance criteria for both requirements 19 and 34.

The final results of these tests proved that the wheelchair modification is able to satisfy the design requirements presented by the client, mainly that the wheelchair can hold a weight of 300 lb. while also being safe and effective for the users. This was the estimated performance based on the wheelchair modification design. The weight requirement was one of the primary focuses during modeling of the wheelchair modification. Model arrangement and structure as well as chosen materials were utilized in order to allow the wheelchair modification to satisfy these requirements.

The discrepancies in these results can be due to the simplification of the 3D model that needed to be used for the finite element analysis. Document 805.30 and 806.30 further explain the necessity of the model simplification. Along with model simplification, boundary and loading conditions may not accurately represent normal use of the wheelchair modification. Due to the knowledge of the EDS team as well as the abilities of the ANSYS Workbench 17.2, assumptions such as utilization of isotropic elasticity as well as pressure applications were used. As a result of the simplifications to the model that were used for stress analysis of the wheelchair modification, some of the results may not be accurate to the physical model.

A possible suggestion to reduce discrepancies is to complete stress simulation on the full 3D model, including all final features and designs as well as more exact force and pressure

applications. Another suggestion is that stress analysis could be completed at the varying reclining angles of the chair.

## PROGRESS

The specifications that were considered for this wheelchair modification were stored in the EDS Design History File in document 505.00. These specifications followed the outline provided by the project sponsor, Dr. James Keszenheimer. Due to the time-constraints and available equipment, some of the specifications were not able to be implemented in the EDS design. Most of the specifications that were not directly implemented, may have been indirectly implemented through various design features. The EDS team took on the mentality that what could not be implemented through the 30-week timeline, could be implemented by the Ukraine manufacturers before mass distribution. Although the specification template contained many details, only a few were not implemented directly.

Diagrammatic labels were not implemented into the final wheelchair modification. The labels were an initial thought to the EDS team based on the difference in language from US and Ukraine users. The team did not provide these diagrammatic labels onto the 3D or physical model but provided all drawings and documents that can be used for indication and use of the wheelchair modification. The EDS team has provided images such as seen below in Appendix K Figure 1 that shows the final folded up design of the wheelchair modification so that users can have an idea of how to use the chair. All safety labels and other regulatory labels that need to be present on the wheelchair is up to the discretion of the Ukraine manufacturer.

Based on the testing equipment that was available to the EDS team, the life requirements of the wheelchair modification were not able to be implemented or tested. During the design phase, the materials were chosen to allow a lifetime usability of ten years. However, the testing required to prove that the EDS wheelchair modification can actually attain this lifetime usability was not able to be performed. These tests will need to be completed by the Ukraine manufacturer.

It was noted in document 205.00 Client Interview Notes, that it “would be nice” to have varying sizes of the wheelchair modification. This was noted in the specification template based on the early ambitions of the EDS team. However, it was not implemented by the EDS team in the final 3D and physical model.

Some of the environmental requirements were implemented such as the operating temperature levels in requirement 23 of the verification matrix. However, the humidity, noise, and vibrations requirements detailed in the specification template were not directly applied to the wheelchair modification. It was assumed that the materials chosen for the wheelchair modification would operate under the specified humidity levels, but it was not verified. The assumption was based on the fact that the aluminum chosen is an extremely popular material in The United States. The noise level was not tested by the EDS team, but was assumed that normal operation levels would be implemented. The reduction of vibration on the wheelchair modification was implemented through the padding of the wheelchair. Again, this was not able to be tested, but assumed to have been implemented into the design indirectly.

The initial goal for this project was to provide an entire physical wheelchair with modifications that would be beneficial for the Ukrainian caregivers. The team produced functional physical components, and the clients were satisfied with these results.

Finally, based on conversation with client Scott Yount, it was decided that the EDS team did not need to abide by ISO 7176. Although this would have been beneficial, the client was not concerned based on the fact that the standards in Ukraine are much less strict and seem to be unenforced.

## INDIVIDUAL CONTRIBUTIONS

Throughout the design process, all team members contributed to the finalization of deliverables. Roles were presented to individual team members, but the roles did not define all of the responsibilities each member embraced over the design period. The roles for the team members can be found in Appendix L Table 1.

In order to better understand each team member's contributions to the design process as well as deliverables, each member was required to track his/her hours in a live document. The document included a description of the task as well as date and time contributed. The hours logged in this live document were then transferred into document 007. Project Work Distribution Form that can be found in Appendix O Table 1. The timeline for deliverables was presented in the form of a Gantt Chart that was updated throughout the semester. Both of these documents were stored in the EDS Design History File.

## FINANCIAL CONSIDERATIONS

EnGenious Design Solutions was given an initial budget of $500 from The University of Akron for this senior capstone project. God's Hidden Treasures provided EDS an additional $1000. Of this budget, around $487 was used or was planned on being used at the time this report was submitted. The full budget breakdown can be seen in Appendix N. The target price for the product, as shown in Appendix C, was given as $300. Based on the product provided by EDS, the manufacturers in Ukraine will be able to produce a product within this price range. Part of the budget was spent by EDS on similar wheelchair products. These products provided parts and information of equivalent designs. As shown in Appendix F, there is great sustainability for this product as well as sales potential based on the large need for wheelchairs in Ukraine. This need will always be large as every year more people with disabilities are born. As far as product margins and return on investment, this is not a main concern of God's Hidden Treasures as they are a nonprofit organization.

Competitive products were researched and stored in the EDS Design History File in document 301.00. The main competitive product that is used by God's Hidden Treasures is donated chairs from Joni and Friends. Although these chairs are donated, the EDS wheelchair modification provides varying advantages such as allowing jobs to be brought to Ukraine to boost the economy. The current donated chairs are manufactured in other countries, and therefore have no cost to the Ukraine. The EDS chair will require manufacture and thus will have a cost; however, this cost will be offset by the boost to the Ukrainian economy through the creation of local jobs. Another advantage of the EDS wheelchair modification is the lifetime of this product will decrease the number of chairs that need to be distributed each year. The reduction in chairs needed will help make distribution more manageable. Finally, the durability of the EDS design includes casters and larger rear wheels that are better than the current chair in maneuverability and withstanding varying terrains.

## SUMMARY FEASIBILITY DISCUSSION

Due to time constraints, the requirements were not verified on a physical model, but through a 3D model. The main requirements brought to the team by client, Scott Yount, were satisfied through analyzation of the 3D model. To review, these requirements included a wheelchair modification that could hold weight up to 250 lbs., wheels to traverse rough terrain and improve steering, improved comfort, collapsibility, lightweight, and low cost. Another important requirement was the ability for the chair to be manufactured in Ukraine. The EDS wheelchair modification was able to satisfy all of the above needs based on varying features and qualities of the wheelchair modification as shown in Appendix M Table 1.

At the end of the project, functional physical components and assembly drawings were provided to Ukraine. The EDS designers worked with the manufacturing engineers in order to design the wheelchair modification under the assumption that simple machines would be available in Ukraine to manufacture the chair. Therefore, the wheelchair modification design was based on utilizing a simple manufacturing process (lathe, mill, pipe bender).

The main purpose of this project was to create a wheelchair modification that would perform better than what is currently being used in Ukraine as shown in Appendix A. The EDS wheelchair modification is a better performing wheelchair based on verification results and knowledge of other transport chairs that are used throughout the world. Therefore, the needs of the project were satisfied by this EDS wheelchair modification.

The resulting product created by EDS has been qualified as a prototype as it is some type of physical model (Haik, Sivaloganathan, & Shahin, 2018). It is important to note that the satisfaction of the varying design requirements as shown above proves that there are several aspects present in the product model. The EDS team focused on creating a beta prototype which was provided to the client in order to identify any remaining design flaws before committing to further production (Haik, Sivaloganathan, & Shahin, 2018). The prototype type was further defined as a proof of product because this beta prototype clarified a design's physical embodiment and production feasibility (Haik, Sivaloganathan, & Shahin, 2018).

## FUTURE WORK

This current group of undergraduate students was not the first group to take on this project. The previous group of students provided God's Hidden Treasures with a 3D model but was unable to produce physical components. The EDS team was able to provide functional physical components to God's Hidden Treasures.

Future considerations would be to conduct more involved testing. The EDS team was unable to perform in-depth testing and designated this testing to be completed by the Ukraine manufacturer. These future steps could include validation testing as well other verification testing such as creep and cyclic loading.

Based on the deliverables provided by EDS, another team could continue the effort of this wheelchair modification by creating varying sizes of the current model created. This may be a difficult project in the scope of manufacturing but would be simple in regard to the design process. The EDS team believes that this would be the next logical step of this project as it was mentioned by the clients that different sizes would be "nice to have".

Another future consideration that could result from this initial wheelchair modification would be through the feedback from God's Hidden Treasures on the deliverables provided by the EDS

team. One of the requirements stated by Scott Yount was the ability for the wheelchair modification to be produced in Ukraine. The EDS team took this into consideration by creating components that can be manufactured with simple access machines. However, a step that could be taken in the future would be to adjust the manufacturing process in order to provide the most efficient production for the Ukraine manufacturer hoping to achieve Six Sigma quality.

Another point of research in regard to this wheelchair modification could involve the necessity for varying reclining positions. For example, “Are three positions needed or only two”? This would involve research with the users and caregivers as well as Scott Yount, which could pose issues based on language barrier and significant time difference. However, this could provide valuable insight into future design considerations for the wheelchair modification.

## DISCUSSION

There were varying issues that arose during the development phase such as client communication, applicable regulations, and testing abilities. As a result of the main client contact living in Ukraine, maintaining consistent client communication was a challenge. Scott Yount was extremely responsive, but it was often difficult to find a time that worked for both parties to discuss aspects of the project, as there is a 6-hour time difference between the United States and the country of Ukraine. Along with the location and communication issues, there was also the lack of Ukraine manufacturing knowledge. As one of the requirements of this project was for the wheelchair modification to be mass-produced in Ukraine, EDS initially tried to set up a meeting with an engineer in Ukraine. Due to the language barrier, the team was unable to meet with the engineer in Ukraine. The team then tried to provide questions to Scott Yount to then provide to an engineer, however the responses were never given to the EDS team. Therefore, it was decided by EDS that the product drawings would be detailed enough as to allow for reproduction.

In regard to regulations, EDS was unsure which standards would apply to this project and if the standards would even be used for this project, as mentioned previously. The team spent significant time researching regulations and even reached out to varying contacts in order to figure out what standards would apply. Once it was decided that ISO 7176 would be the most applicable, the team then spent time understanding if the standard should be used for this senior capstone project. Some team members reached out to past co-workers to see if the standard could be provided for the team to view, as it was expensive to purchase. After the team explored all options, the client finally decided that the standard did not need to be utilized for this portion of the wheelchair modification project. However, some of the specifications were used as guidelines for safety factors and other safety precautions while designing the chair.

In the initial stages of the design process, the EDS team realized that the specification values would eventually need to be verified. During the verification phase of this project, it was determined that the team would be unable to perform full scale verification testing on the physical model. In order to provide verification, testing was completed on the 3D model based on the test plan. The EDS team carried out the initial three phases which included attribute inspection, measurement inspection and analysis, and functionality analysis. The final three phases which include functionality demonstration, manufactured measurement evaluation, and aesthetic evaluation must be completed by the Ukraine manufacturer. This is noted in the verification matrix in Appendix E. By completing the initial testing phases, verification was completed for this senior capstone project. These testing phases allowed the EDS team to

utilize measurement tools in SOLIDWORKS as well as stress analysis through finite element analysis.

The senior capstone course involved team meetings, team member division of labor, purchasing, and guidance. The course length was over two semesters, but the EDS team believed that it was hard to truly begin modeling and fabrication until too late in the second semester. This group of undergraduate students believed that it would be beneficial for future students to start documentation and project selection in the year before the senior design project is completed, similar to the Electrical Engineering discipline. The team meetings were frequent in the first semester as there were plenty of deliverables that were divided among team members. In the second semester, the entire team did not meet very frequently because tasks were divided among individuals and then submitted throughout the semester. If any EDS team member felt that an entire team meeting was needed, the meeting was scheduled. The EDS team members all varied in strengths and weaknesses. Therefore, the division of labor was based on the strengths of the members. For example, one member was talented in fabrication and became the leader in regard to prototype fabrication. Another team member was talented in documentation and lead the team in deliverable creation and DHF organization. One team member took the lead on purchasing of parts and was able to create a very efficient communication relationship with the engineering technician as well as the lead machinist in the manufacturing workshop in the Mechanical Engineering department. Although there were a few mentors that provided guidance to the team throughout the year, the EDS team believed that more guidance would be beneficial to future design teams. A teaching assistant was utilized in the first semester of this wheelchair modification and provided extensive guidance to the team. It would be helpful if a teaching assistant was utilized throughout the entire year to not only assist with upcoming deliverables, but to also provide feedback on already delivered documentation. There were times where confusion arose because the EDS team was unsure if deliverables were completed correctly. Based on engineering co-op experiences, the EDS team was familiar with receiving feedback from management. This was not always the case in the senior design course.

In regard to future improvements for the capstone course, the EDS team believed that early project initiation as well as deliverable feedback would provide the most benefit for future students. A few team members thought that it would be beneficial to imitate a fully functional business unit that works on only one or two products over the entire year. In this format, students could flourish in an area that truly interests him/her.

## LESSONS LEARNED

The EDS team learned how to stay true to the project scope and minimize project scope creep. As this project was tiered towards helping those less fortunate in the Ukraine, it was easy to imagine having a design that included all needs, wants, and wishes. But the EDS team learned early on that not everything could be accounted for in this senior capstone design. The team learned to stay true to the needs outlined in the client interview and translate those needs to the requirements for the design. The EDS team also learned that the design process is truly an iterative one, where verification, validation, and fabrication can result in design changes. The team learned to understand the reason for the design change and the best way to implement the needed change to the design. Finally, the team learned that more time should be set aside for the fabrication process of the prototype.

## CONCLUSION

Based on the production of functional physical components as well as the well-documented Design History File, the EnGenious Design Solutions team was able to satisfy design requirements regarding a wheelchair modification prototype for God's Hidden Treasures. These requirements included a durable, lightweight, low-cost, and comfortable wheelchair with improved steering/maneuverability that is able to be produced in Ukraine. This wheelchair modification prototype as well as drawings, documentation, and intellectual property were provided to God's Hidden Treasures in order to mass produce and sell in Ukraine.

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# Appendix A: Current Product

*Figure 1: Current wheelchair used in Ukraine.*

# Appendix B: Client Requirements

| Question | Customer Statement | Interpret Need | Importance |
|---|---|---|---|
| Typical Uses | Playing games<br>Transportation<br>All day seating for children | Easy to maneuver<br>Easy to transport<br>Foldability<br>Comfortable for children | Must<br>Must<br>Must<br>Should |
| Likes | Seating for children<br>Straps are available<br>Price<br>Variability for seat position | Low Budget (<$300)<br>Allow seat position to be changed | Must<br>May |
| Dislikes | Lack of steering<br>Size is too large for elevators<br>Not portable<br>Weight<br>Strap Mechanism<br>Footrest<br>Only one size<br>Material can't be taken off<br>Small wheels | Steering ability<br>Wheel movement<br>Portability<br>Fit into elevators<br>Light weight<br>Single footrest<br>Strap ability to change<br>Different sizes<br>Removable material<br>Securability<br>Larger wheels | Must<br>Must<br>Must<br>Must<br>Must<br>Should<br>May<br>Should<br>Should<br>Should<br>Must |

*Table 1: Client Requirements Breakdown where "must" = need, "should" = would be nice, "may" = if possible*

# Appendix C: 206.00 Requirements

**1.0 User/patient/clinical performance characteristics (Scott Yount)**

- Strong enough to hold weight range of 0-250 lbs. (0-113 kg)
- Wheels able to traverse rough terrain and improve steering/maneuverability
- Improved comfort
- Ability to collapse into a smaller size
- Lightweight but still rigid
- Low-cost (<$300)

**2.0 Privacy and security**

- This device will not require any specific consideration related to the client

**3.0 Safety**

- Mechanical
  - Wheels are to contain a brake/locking mechanism
  - Chair is to require a safety lap or chest harness
  - Base needs to be wide enough to prevent tipping
  - Padding/Wheels need to damper continuous and excessive vibrations
- Material
  - Frame must withstand continuous vibration and impact
  - Cloth must prevent irritation when in contact with skin
  - Cloth must prevent overheating
  - Cloth must be able to be washed to prevent bacterial build up

**4.0 Regulatory**

- Specifications of standards for Ukraine were not mentioned.
  - Standards will be based off of OHSA specifications to meet the team's regulatory standards

**5.0 Quality**

- Materials must be able to provide a sturdy frame
- Fabric must be durable and wear resistant, along with capable of being cool

**6.0 Reliability**

- Able to operate on various terrains
- Can withstand a variety of weather
- Product should be durable and able to handle normal wear and tear

**7.0 Compatibility with accessories/auxiliary devices or products**

- No Modifications with existing products
- Develop a whole new prototype of the product

**8.0 Compatibility with the intended environment**

- Compatible with Temperature ranges of -20°C to 35°C
- Functioning on/in rain, snow and ice

**9.0 Human factors**

- Easily transportable
- Light weight
- Capable of fitting into a standard sedan
- Adjustable for ages 5-35

**10.0 Physical characteristics**

- Increased padding for resting for long periods of duration
- Preferred single footrest
- Swivel front wheels for easy turning
- Sturdy

- Cool fabric for warm weather
- Capable of fitting on small Elevators
    - Door: 60 cm wide
    - Elevator dimensions: 110 x 90cm

**11.0 Sterility**

- Washable Pads
- Removable features that are able to be cleaned

**12.0 Manufacturability**

- Able to be built in Ukraine

**13.0 Serviceability**

- Device easily taken apart to be serviced

**14.0 Requirements for intended markets (domestic or international)**

- Marketing specifically for patients with disabilities
- Price around $300 (ideal)

# Appendix D: Test Phase Explanations

**Attribute Inspection (AI):** This testing phase will verify that certain key attributes/components are present in the final product design. Visual inspection as well as CAD model inspection will be utilized as the main test methodology for this phase.

**Measurement Inspection and Analysis (MIA):** This testing phase will verify varying component measurements. Some component measurements are required for aesthetics whereas others are required for functionality. Regardless of the reason for the needed measurement, the test methodologies will include computer aided design (CAD) model analysis tools.

**Functionality Analysis (FA):** This testing phase will verify functional requirements through analysis methods. The test methodology that will be used is ANSYS Workbench 17.2 as well as analysis aspects of SOLIDWORKS. The ANSYS Workbench 17.2 program application will allow EDS to perform finite element method analysis on varying components of the product. The ANSYS website contains the Simulation-Drive Product Development business (ANSYS, Inc., 2019) asset that allows for engineering simulation. The site continues to explain that “the software enables you to test thousands of designs in the time it used to take to build a single prototype”. Therefore, as a result of the time constraints, finite element methodology will be used through ANSYS Workbench 17.2. Analysis tools that are available in SOLIDWORKS including material inspection and assembly weight will be utilized.

**Functionality Demonstration (FD):** This testing phase will verify functional requirements through demonstration. The demonstrations will be performed team members with at least one team member recording the results. Demonstrations vary from pushing the product to turning the product and even folding the product.

**Manufactured Measurement Evaluation (MME):** Once the product is manufactured, all previous measurement analysis will be completed again using the finalized product. This phase of testing is crucial into understanding if the manufacturing process delivered a reliable product according to the product drawings. The test methodology that will be used for this phase will include physical measurement testing with tools mentioned in the above section.

**Aesthetic Evaluation (AE):** This testing phase will verify that the aesthetics of the product are approved by the client. There is only one requirement that is covered by this testing phase and is indicated in the Verification Matrix by “AE”.

## Appendix E: Verification Matrix

| Requirement Number | Specification Document Location | Requirement Key Phrase | Design Requirement | Pass/Fail Criteria | System Component | Test Results | Pass/Fail Comments | Team Member Signoff with Date | Testing Phase |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Table 1 Function Priority Table | Recline to 115 | Back seat plate must recline from 90° position to a minimum of 115° | Chair reclines to 115° ± 5° | Wheelchair Modification | Results documented in 806.20 | Pass | SJC TMV 4/2/2019 | MIA |
| 2 | Table 1 Function Priority Table | Fold to 90 | Seat plate is capable of folding upwards to 90° | Back plate folds to 85° ± 5° | Wheelchair Modification | Results documented in 806.20 | Pass | SJC TMV 4/2/2019 | MIA |
| 3 | Table 1 Function Priority Table | Leg Swing | Front legs are able to swing down to decrease overall size when folded | Folded product size is laterally smaller than the unfolded product size. | Wheelchair Modification | Results documented in 806.20 | Pass | SJC TMV 4/2/2019 | MIA |
| 4 | Table 1 Function Priority Table | Seat Belt | Product will have seat belt to restrain movement | Product design contains seat belt availability for add on by user. | Fabric Seat Back | Results documented in 806.10 | Pass | WJR TV 4/4/2019 | AI |
| 5 | Table 1 Function Priority Table | Caster | Product will contain casters to assist in maneuverability | Product design contains casters. | Front Legs Assembly | Results documented in 806.10 | Pass | WJR TV 3/26/2019 | AI |
| 6 | Table 1 Function Priority Table | Rolling Wheels | All four wheels are capable of rolling to transport the product with little resistance | All four wheels are utilized in product rolling. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | FD |
| 7 | Table 1 Function Priority Table | Pad Comfort | Pads will be soft for patient comfort | Pads must be at least 2 inches thick in padding. | Seat Padding | Results documented in 806.20 | Pass | WJR TV 3/26/2019 | MIA |
| 8 | Table 1 Function Priority Table | Pad Detach | Pads can detach so that they can be washed | Pads must detach from overall product. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | FD |
| 9 | Table 1 Function Priority Table | Handle Grip | Handles are able to provide a gripping area so that the product can be pushed | Gripping area length of 2.91 ± .50 inches present on handles. (Choosing Hand Tools. (n.d.). Retrieved from https://choosehandsafety.com/choosing-hand-tools/hand-tool-size) | Handle Assembly (R & L) | Results documented in 806.20 | Pass | WJR TV 3/26/2019 | MIA |

| Requirement Number | Specification Document Location | Requirement Key Phrase | Design Requirement | Pass/Fail Criteria | System Component | Test Results | Pass/Fail Comments | Team Member Signoff with Date | Testing Phase |
|---|---|---|---|---|---|---|---|---|---|
| 10 | Table 1 Function Priority Table | Brakes | Ability for rear wheels to be locked in place | Brake system prevents rear wheel rotation with 5 N (1 lb.) of applied force. (Du, Z., Fan, Y., Sullivan, C., Wen, & Yilong. (2010). Safety Stroller. Ann Arbor: Department of Mechanical Engineering, University of Michigan) | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | FD |
| 11 | Table 1 Function Priority Table | Vibration Reduction | Padding on chairs must dampen vibrations | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. |
| 12 | Table 1 Function Priority Table | Pad Ventilation | Pads utilized on product must be able to ventilate | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. |
| 13 | Table 1 Function Priority Table | Lock and Release Pin | Quick release pins will be utilized to lock and release the frame from collapsing | The quick release pins lock the frame and maintains the product locked position for at least 5 min during normal product use (pushing 250 lb. user). | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | FD |
| 14 | Table 1 Function Priority Table | Foot Plate | A foot plate will be added to provide a place for the patient's legs to rest on | Single footplate with depth of ≤18 ± 1 cm (PROACTIV. (n.d.). // One-Piece Footrests. Retrieved from PROACTIV: https://www.proactiv-gmbh.com/wheelchair-footrests-one-piece.php) | Foot Plate Assembly | Results documented in 806.20 | Pass | SJC TMV 4/2/2019 | MIA |
| 15 | 2.4 Assumptions 5.2.3 Size, Shape, Weight and Color | Doorway Fit/Product Width | Product must fit in doorways that have a minimum width of 23.6 inches. | Product width is ≤ 23.4 ± .1 inches. | Wheelchair Modification | Results documented in 806.20 | Pass | WJR TV 3/26/2019 | MIA |
| 16 | 2.4 Assumptions | Seating Width | Patients width is maximum of 16 inches at the hip area | Product seat area is ≤ 15 ± 1 inches. | Seat Assembly | Results documented in 806.20 | Pass | WJR TV 3/26/2019 | MIA |
| 17 | 2.4 Assumptions5.2.3 Size, Shape, Weight and Color | Product Weight | Users can lift a maximum of around 40 lbs. | Product weight ≤ 40 ± 2 lbs. | Wheelchair Modification | Results documented in 806.20 | Pass | WJRTV3/26/2019 | MIA |
| 18 | 2.5 Constraints | Product Load Bearing | Product must be able to sustain 250 lbs. of user weight. | Product moves user of ≤ 250 lbs. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | FD |

| Requirement Number | Specification Document Location | Requirement Key Phrase | Design Requirement | Pass/Fail Criteria | System Component | Test Results | Pass/Fail Comments | Team Member Signoff with Date | Testing Phase |
|---|---|---|---|---|---|---|---|---|---|
| 19 | 2.5 Constraints | Product Load Bearing | Product must be able to sustain 250 lbs. of user weight. | Safety factor of 2.5 ± 1 is demonstrated with 250 lb. distributed load (Engineering Toolbox, 2010) | Wheelchair Modification | Results documented in 806.30 and 806.30_V2 | Pass | KJH<br>TV<br>4/1/2019 | FA |
| 20 | 3.1.1 Customer Requirements | Product Turn | Product must contain front wheels that allow turning ability. | Product turns within 3 seconds of applied force. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | FD |
| 21 | 3.1.1 Customer Requirements | Hand Brakes | Product must have hand brakes. | Hand brakes are attached at the handles of the product. | Handle Assembly (R & L) | Results documented in 806.10 | Pass | WJR<br>TV<br>3/26/2019 | AI |
| 22 | 3.2.3 Supportability Requirement | Mating | Mating components are able to be mass manufactured. | Main mating components at MMC and LMC are both satisfied for mass manufacturing. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. |
| 23 | 3.4.1 Operating and Storage Temperature Levels | Temperature Operation | Product can operate in temperatures ranging from -10°C to 40°C. | Temperature range for materials selected is between -10°C and 40°C. (WeatherOnline, 2019) | Wheelchair Modification | Results documented in 806.30 | Pass | KJH<br>TV<br>3/26/2019 | FA |
| 24 | 3.4.2 Operating and Storage Humidity Levels | Humidity Operation | Product can operate normally under 40-50% humidity | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. |
| 25 | 3.4.5 Exposure to Dirt and Other Contaminants | Dirt and Contaminants | Product does not fail due to dirt, concrete, brick. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. |
| 26 | 4.1 Portability | Folded Thickness | Product will exhibit final thickness ≤ 18 inches. | Folded product thickness is ≤ 17.5 ± .50 inches. | Wheelchair Modification | Results documented in 806.20 | Pass | SJC<br>TMV<br>4/2/2019 | MIA |
| 27 | 4.3 Usability | Product Maintenance | Regular maintenance should be required for less than five parts. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. |
| 28 | 5.2.3 Size, Shape, Weight and Color | Product Length | Greatest length of product will be 35.43 inches. | Greatest allowable length of product will be 35.43 inches. | Wheelchair Modification | Results documented in 806.20 | Pass | WJR<br>TV<br>3/26/2019 | MIA |
| 29 | 5.2.3 Size, Shape, Weight and Color | Aesthetics | Product must be aesthetically pleasing. | Overall average aesthetic grade of 3/5. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | AE |
| 30 | 5.4.3 Priorities Imposed by Types of Input | Fold Time | Product will fold within five seconds. | Product can fold in ≤ 5 seconds. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | FD |

| Requirement Number | Specification Document Location | Requirement Key Phrase | Design Requirement | Pass/Fail Criteria | System Component | Test Results | Pass/Fail Comments | Team Member Signoff with Date | Testing Phase |
|---|---|---|---|---|---|---|---|---|---|
| 31 | 5.5 Reliability | Lifetime | Product lifetime is 10 years. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. | Must be done by Ukraine manufacturer. |
| 32 | 5.5.1.1 Wheels | Wheel Bearing | Casters can withstand 100 lbs. Back wheels can withstand 200 lbs.. | Casters do not achieve yield stress with 100 lb. distributed load.<br><br>Back wheels do not achieve yield stress with 200 lb. distributed load. | Back Leg Assembly<br><br>Front Leg Assembly | Results documented in 806.30 | Pass | KJH<br>TV<br>3/26/2019 | FA |
| 33 | 5.5.1.1 Wheels | Wheel Material | Wheel will be made of rubber to decrease the risk of becoming flat. | Rubber material utilized for wheels. | Rear Wheels Front Casters | Results documented in 806.10 | Pass | WJR<br>TV<br>3/26/2019 | AI |
| 34 | 5.5.1.2 Frame | Entire Frame Bearing | Frame can hold up to 300 lbs. | Frame does achieve yield stress when exhibited to 300 lb. distributed load. | Wheelchair Modification | Results documented in 806.30 and 806.30_V2 | Pass | KJH<br>TV<br>4/1/2019 | FA |
| 35 | 6.2 Safety Regulations | Pinch Point Cover | Material will cover pinch points detailed by team. | Pinch points of product are covered with material. | Wheelchair Modification | Results documented in 806.10 | Pass | WJR<br>TV<br>3/26/2019 | AI |

# Appendix F: Business Aspects

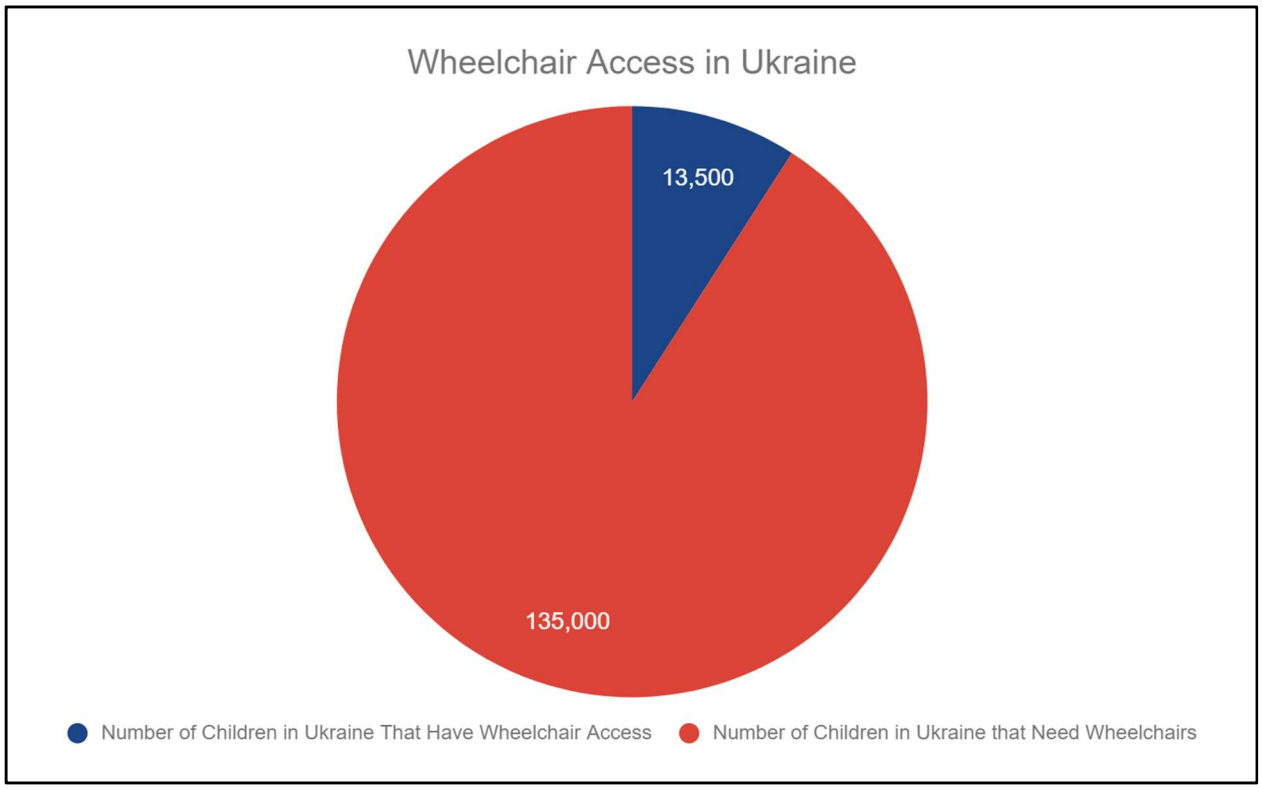



*Figure 1: Wheelchair Access in Ukraine*

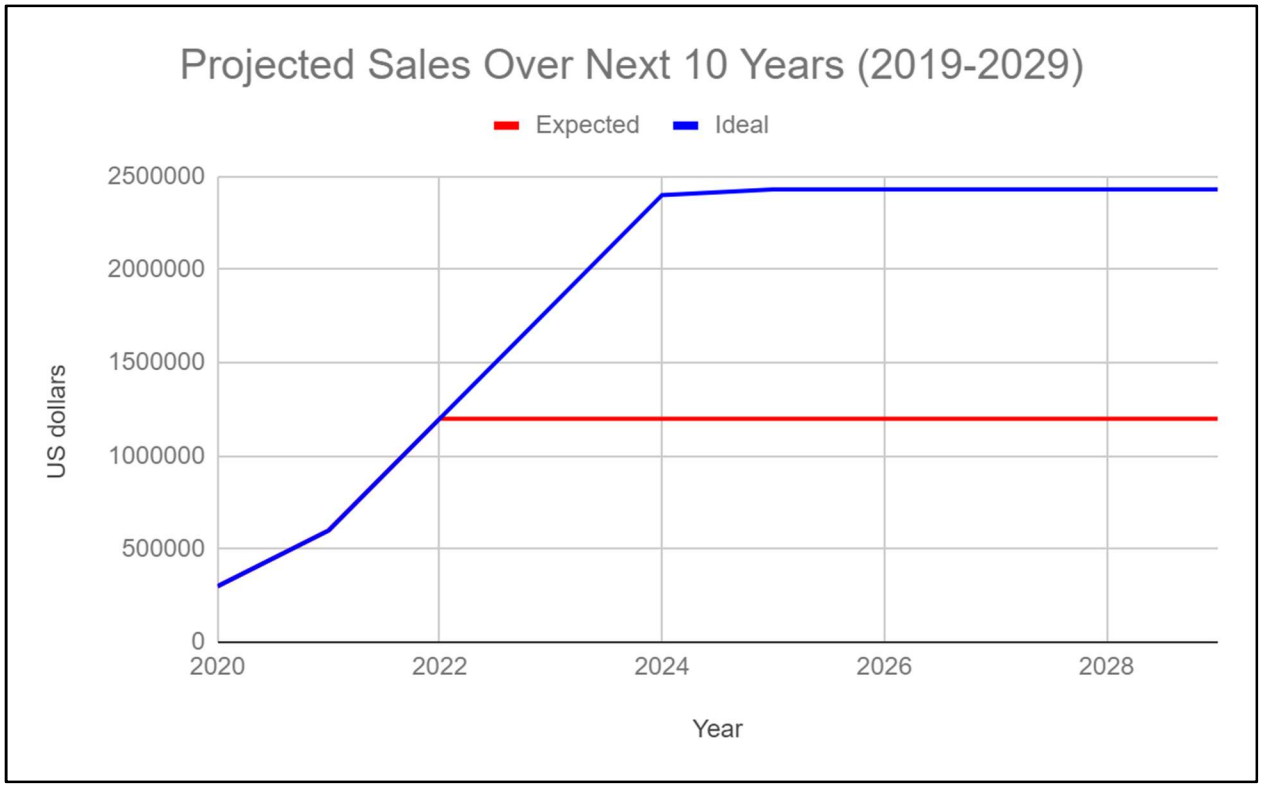


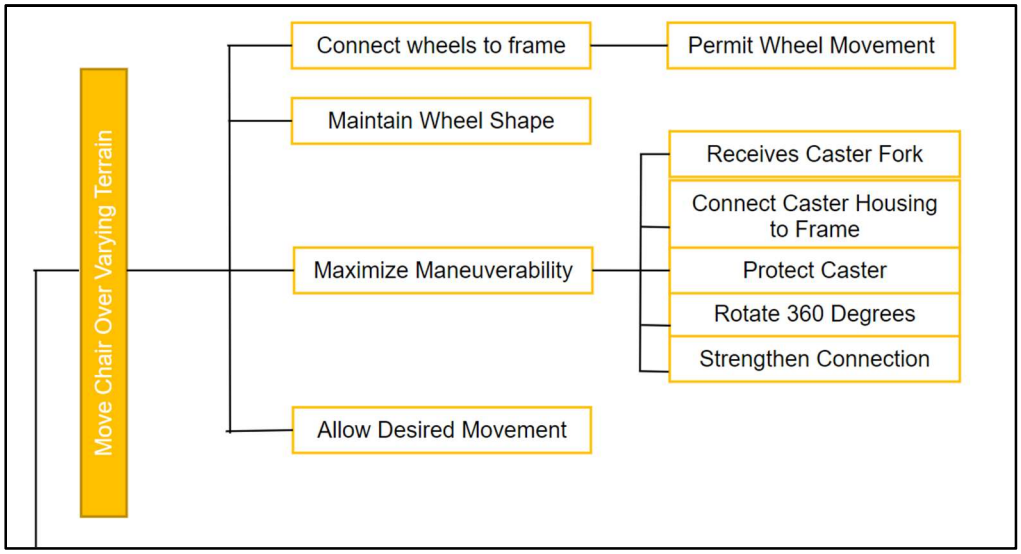

*Figure 2: Projected Sales*

| Survey Questions | Average | Mode | Standard Deviation |
|---|---|---|---|
| **There are sufficient wheelchairs available for children** | 2.66 | 4 | 1.31 |
| **There are sufficient wheelchairs for adults** | 2.81 | 4 | 1.31 |
| **The different styles of wheelchairs are sufficient** | 2.46 | 2 | 1.11 |
| **The current imported and donated wheelchair fit the needs of all the people with mobility problems** | 3.44 | 4 | 1.23 |

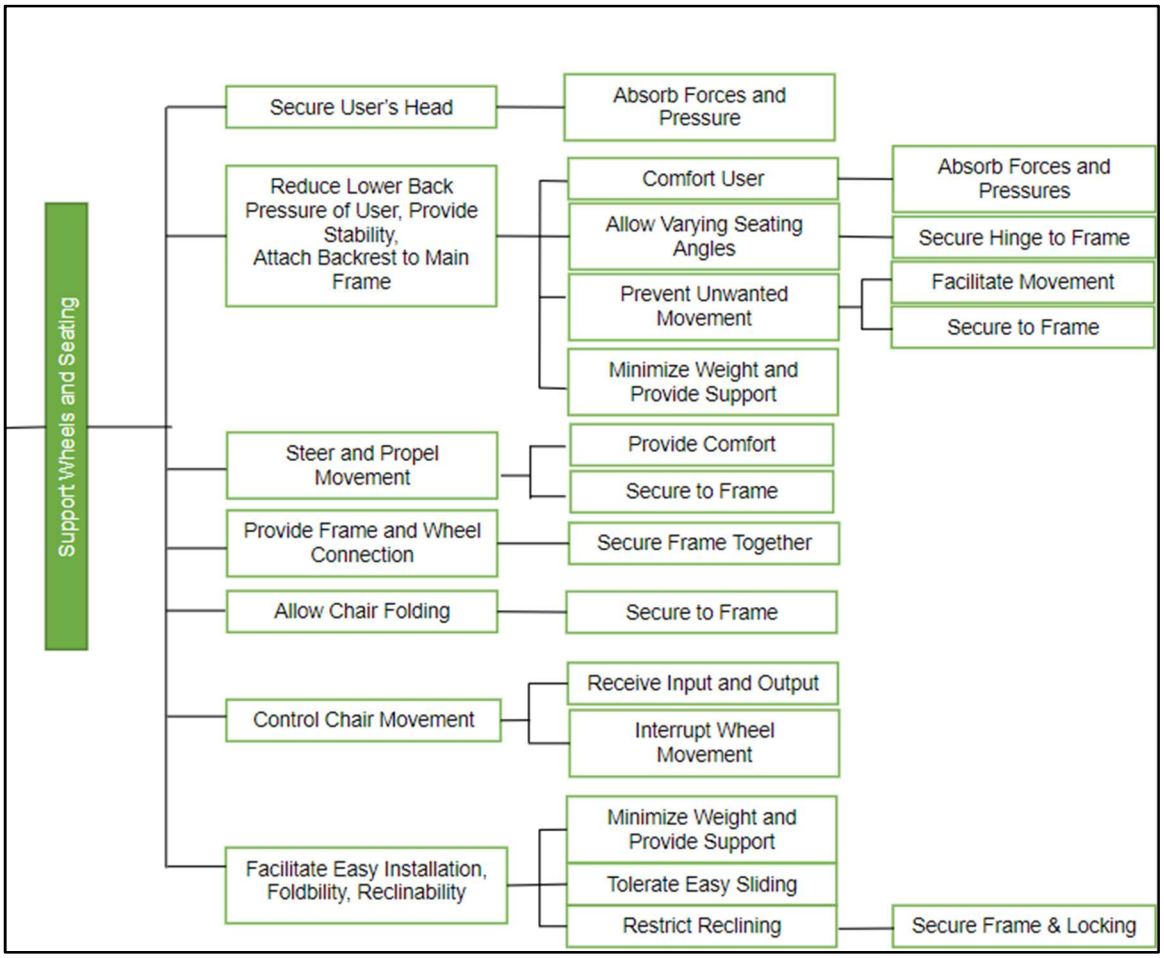
Table 1: Overall Sample Prototype Needs Assessment from Likert Scale Survey, n=90

# Appendix G: Functional Chart

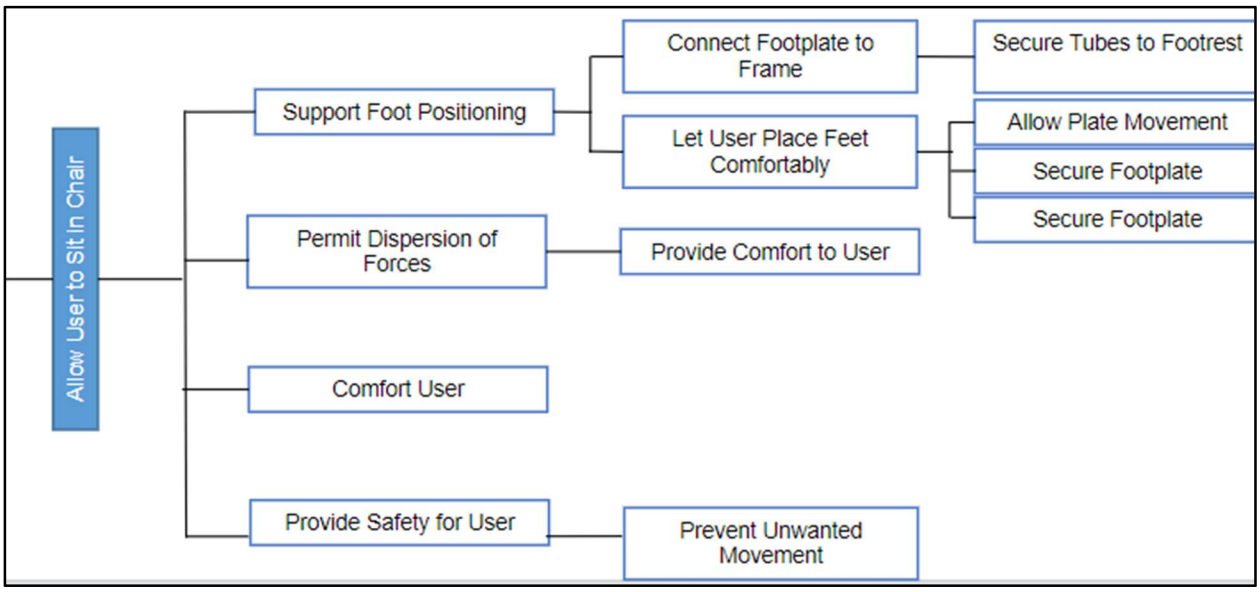
Wheel:



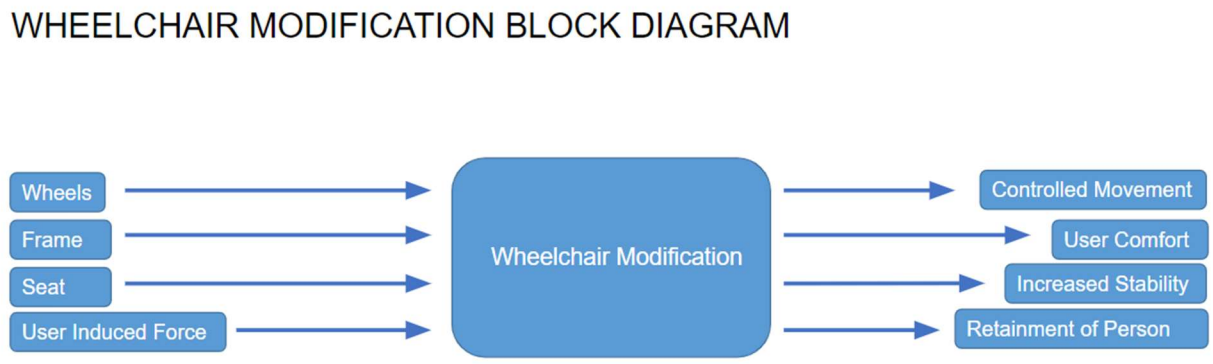

Frame:



Seat:




# Appendix H: Block Diagram



# Appendix I: Wheelchair Modification

Figure 1: 3D Model of Wheelchair Modification

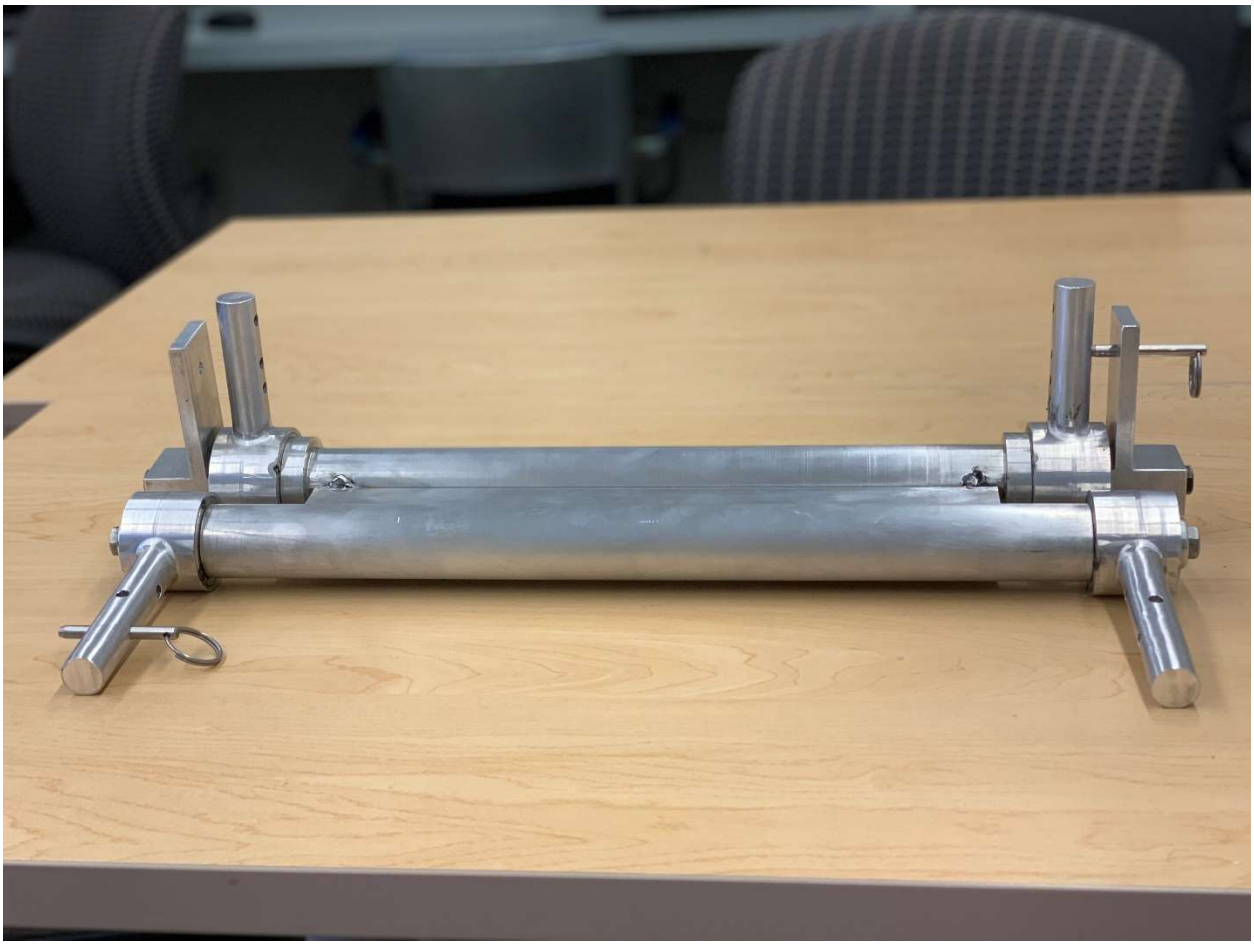


Figure 2: Fabricated Hinge

# Appendix J: Stress Test Results

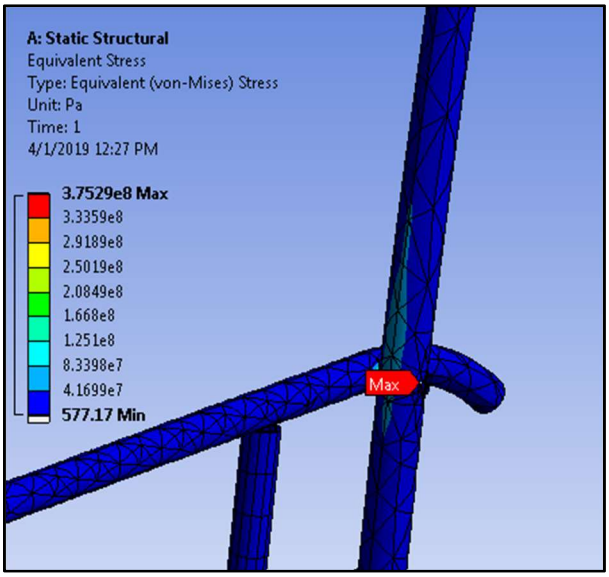



*Figure 1: Finite element results for 805.30 FA Protocol.*

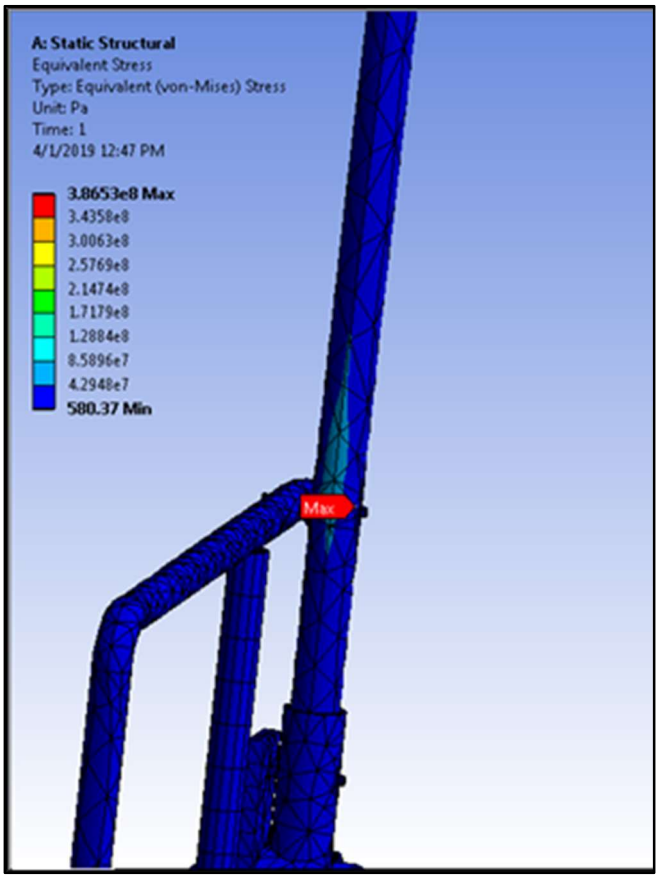



*Figure 2: Finite element results for 805.30_V2 Protocol.*

# Appendix K: Wheelchair Modification - Folded

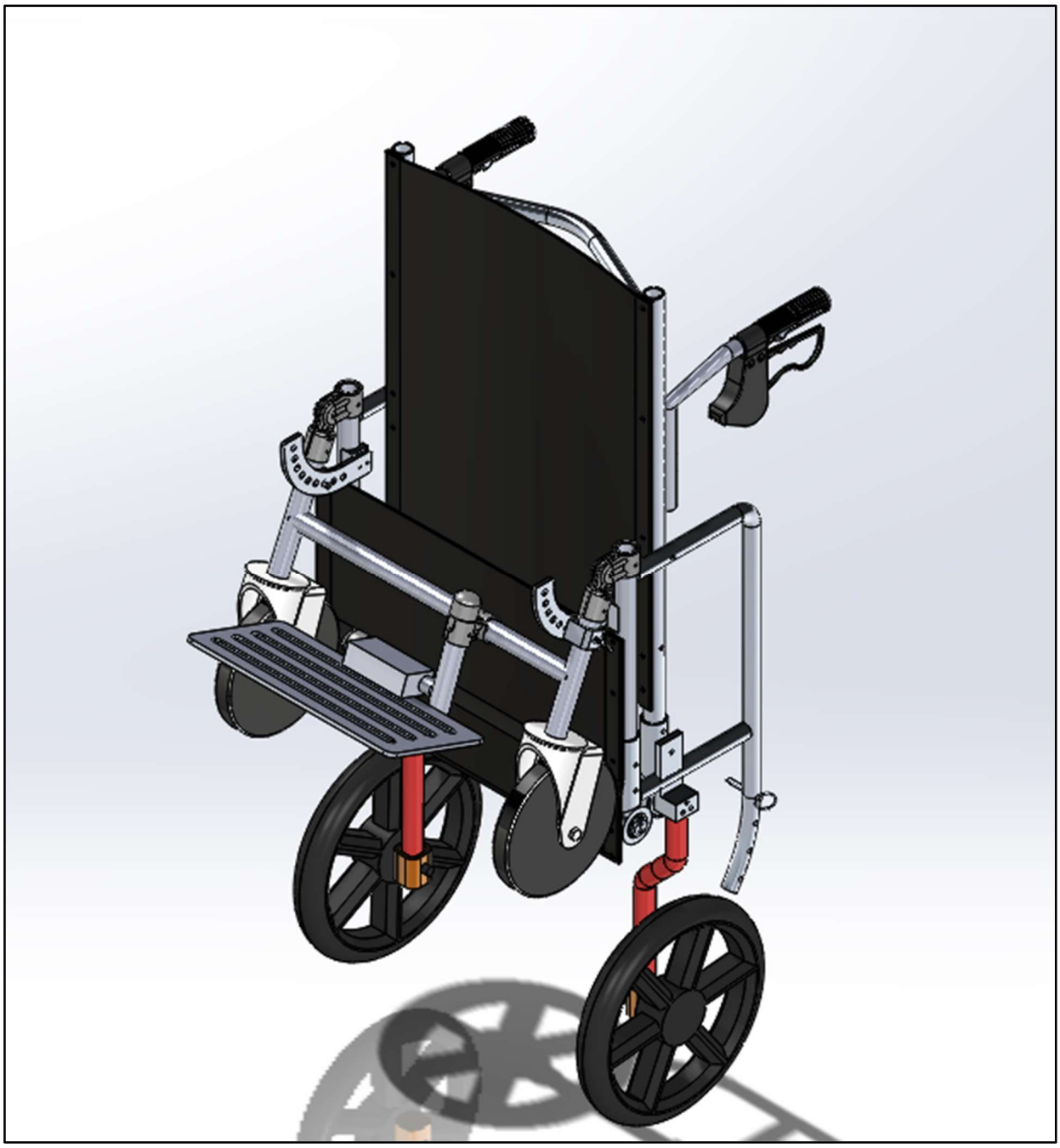


Figure 1: 3D Model of Folded Wheelchair Modification

# Appendix L: Team Member Roles

| **Team Member Name** | **Team Member Role** |
|---|---|
| Taylor Verba | Project Manager |
| Kenneth Hutson | Design/Manufacturing Engineer |
| Nolyn Martz | Design/Manufacturing Engineer |
| William Rasper | Design/Manufacturing Engineer |
| Stephen Conklin | Design Engineer |

*Table 1: Team Member Role Definitions*

# Appendix M: Requirement Satisfaction

| **Design Requirement** | **Satisfied By:** |
|---|---|
| Weight up to 250 lbs. | Materials and structure |
| Improved Steering | Casters to provide varying degrees of freedom and rotation for the front wheels |
| Improved Comfort | Chair reclining ability |
| Collapsibility | EDS hinge design |
| Lightweight | Materials and structure |
| Low Cost | Affordable materials and reusing predicate device parts |
| Ukraine Manufacturability | Utilize machines that are easily accessible |

*Table 1: Requirement Satisfaction*

Appendix N: Project Budget

| Part | Material | Description | Length (in) | Width (in) | Thickness (in) | OD (in) | ID (in) | Nom | Quantity | Supplier | Part # | Unit Cost ($) | Total Cost | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005_05 | 6061-T4 Al | 0.75 Nom. Al Piping | 96 | N/a | 0.11 | 1.05 | 0.82 | 0.75 | 2 | **Spee-D-Metals** | N/A | 19 | 38 | | |
| 2035_10 | | | | | | | | | | | | | 0 | | |
| 2002_01 | | | | | | | | | | | | | 0 | | |
| 2003_01 | | | | | | | | | | | | | 0 | | |
| 2022_04 | | | | | | | | | | | | | 0 | | |
| 2025 p1 | 6061-T4 Al | 0.5 Nom. Al Piping | 96 | N/a | 0.11 | 0.84 | 0.622 | 0.5 | 2 | **https://www.onlinemetals.com** | 1219 | 15.14 | 30.28 | | |
| 2025 p2 | | | | | | | | | | | | | 0 | | |
| 2034_06 | | | | | | | | | | | | | 0 | | |
| 2006_05 | | | | | | | | | | | | | 0 | | |
| 2036_10 | | | | | | | | | | | | | 0 | | |
| | | | | | | | | | | | | | 0 | | |
| 2017_01 | 6061-T4 Al | Bar Stock 1.75x3x36 | 36 | 3 | 1.75 | N/a | N/a | N/a | 1 | **Spee-D-Metals** | N/A | 105 | 105 | | |
| 2014_01 | | | | | | | | | | | | | 0 | | |
| | | | | | | | | | | | | | 0 | | |
| 2009_01 | 6061-T4 Al | Round Bar Stock 2in | 24 | N/a | N/a | 2 | N/a | N/a | 1 | **Spee-D-Metals** | N/A | 43 | 43 | | |
| | | | | | | | | | | | | | 0 | | |
| 2010_01 | 6061-T4 Al | Round Bar Stock 1.5in | 24 | N/a | N/a | 1.5 | N/a | N/a | 1 | **Spee-D-Metals** | N/A | 25 | 25 | | |
| | | | | | | | | | | | | | 0 | | |
| 2032_01 | 6061-T4 Al | .375 Sheet | 12 | 8 | 0.375 | N/a | N/a | N/a | 1 | **Spee-D-Metals** | N/A | 30 | 30 | | |
| 2011_01 | N/A | Large Bearing | N/A | N/A | N/A | 1.625 | 0.75 | N/A | 2 | **McMasterCarr** | 60355k706 | 11.12 | 22.24 | | |
| 2012_01 | N/A | Small Bearing | N/A | N/A | N/A | 2 | 1 | N/A | 2 | **McMasterCarr** | 60355k708 | 13.92 | 27.84 | | |
| 1002_04 | Aluminum | Adjustable angle pipe fitting | N/A | N/A | N/A | N/A | N/A | N/A | 2 | **McMasterCarr** | 2534t33 | 6.4 | 12.8 | | |

| Part | Material | Description | Length (in) | Width (in) | Thickness (in) | OD (in) | ID (in) | Nom | Quantity | | Supplier | Part # | Unit Cost ($) | Total Cost | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1005_10 | Aluminum | Footplate holder | N/A | N/A | N/A | N/A | N/A | N/A | 1 | | **McMasterCarr** | 2534t28 | 3.34 | 3.34 | | |
| 1004_01 | Stainless Steel | Locking Pins | 1.685" | N/A | 1/4 | N/A | N/A | N/A | 4 | | **McMasterCarr** | 98404a137 | 2.06 | 8.24 | | |
| N/A | Stainless Steel | 1/4-20 Bolts (50) | N/A | N/A | N/A | N/A | N/A | N/A | 1 | | **McMasterCarr** | 91251A544 | 12.48 | 12.48 | | |
| N/A | Stainless Steel | 1/4-20 Nuts (25) | N/A | N/A | N/A | N/A | N/A | N/A | 2 | | **McMasterCarr** | 97135A210 | 3.56 | 7.12 | | |
| N/A | N/A | MedLine Chair | N/A | N/A | N/A | N/A | N/A | N/A | 1 | | **Amazon** | B007WA1ZG4 | 97.59 | 97.59 | | |
| N/A | Fabric | Fabric for seat, back rest, seat belt | | | | | | | 1 | | **Amazon/Michaels/Joanns** | N/A | 25 | 25 | | |
| | | | | | | | | | | | | | | | **Subtotal (Estimate):** | **Subtotal (Exact):** |
| | | | | | | | | | | | | | | | **487.93** | **443.33** |

*Table 1: Project Budget Estimate*

# Appendix O: Work Distribution Form

| | PROJECT NOTEBOOK DOCUMENTS | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Prototyping** | | | | **Testing** | | **Business Validation** | | **Miscellaneous Documentation and Reporting** | | | | | | **CDR** | **Capstone Day** | **Video Demo** | | |
| **TEAM # 14** | CAD Drawings | Purchasing Parts | Prototype Fab | Analysis | Test Plan | Test Results | Market Research | Executive Summary | Bill of Materials | Project Budget | Correspondence | Meeting Minutes | Mentor Status Slides | eBinder Organization | CDR Report | Capstone Poster and Setup | Video Demo | TOTAL HOURS | SIGNATURES* (Student ID) See footnote |
| **Taylor Verba** | 0 | 0 | 0 | 2.5 | 9.5 | 16 | 4 | 1.5 | 0 | 0 | 0 | 8 | 1.5 | 8 | 11 | 2.5 | 0.5 | **65** | 2739619 |
| **Stephen Conklin** | 28.25 | 8.25 | 8.5 | 1.5 | 1.75 | 1 | 0 | 0.5 | 0 | 2 | 0 | 4.5 | 1.5 | 3 | 1 | 1 | 1 | **63.75** | 2952453 |
| **Nolyn Martz** | 33.75 | 2 | 24.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5.5 | 0 | 0 | 0 | 1 | 0.5 | **67.25** | 3012179 |
| **Kenneth Hutson** | 27 | 0 | 5.5 | 1 | 1 | 11.5 | 0 | 0 | 0 | 0 | 3 | 5 | 1.25 | 5 | 1 | 1 | 0.5 | **62.75** | 2789553 |
| **William Rasper** | 10 | 0 | 0 | 0 | 1 | 6.25 | 2 | 1 | 0 | 0 | | 11 | 0 | | 0 | 0 | 10 | **41.25** | 2890190 |
| **TASK TOTALS** | **99** | **10.25** | **38.5** | **5** | **13.25** | **34.75** | **6** | **3** | **0** | **2** | **3** | **34** | **4.25** | **16** | **13** | **5.5** | **12.5** | **300** | |

*Table 1: Work Breakdown for Team Members.*