Verification & Evaluation of the Freedom Wheels Project

Emily Caudle

u5182391@anu.edu.au

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Abstract

Riding a bike is a part of growing up though some children struggle to enjoy this experience due to ill health, poor strength and mental limitations. Freedom Wheels is a project that aims to develop a solution for these children and enable them to experience movement, exercise their legs and arms and allow them to share in the same experiences as other children their age would. Technical Aid to the Disabled ACT (TADACT) is a non for profit organisation that creates and modifies everyday equipment to make it accessible for the disabled. This is the client for the project and the designs and ideas developed in the project are done so in accordance with this organisation. This report looks at the work and designs done so far by the Freedom Wheels group and evaluates them to ensure that they meet initial customer requirements while performing to a high standard and are safe for the child to use. The proposed steering designs include a hydraulic system, steering though braking and also a series of cables that can be tightened to turn the bike. Harness solutions include a belt that sits across the waist, a chest loop that comes from an attachment behind the head, below the arms and rests on the torso and also a 5 point harness. Comparisons and evaluations are also made between the proposed design, the current design that is used and a standard bicycle.

Theory Review

Design Verification

The verification process ensures that a product meets the requirements established by the client. A series of tests must be determined, with defined criteria for what is a suitable outcome that satisfies the requirements. These tests can be based off the tertiary attributes of the attributes cascade table, which are all measurable qualities. The tests can also have a pass/ fail criteria for attributes that it may or may not have. The tests can trial and assess the potential designs analytically, by using proof-of-concept or with systems prototypes (Blanchard 2011). Further down the line operational testing (design is out in the real world) and support testing (support is offered to the design user) may be performed (Browne 2013).

For a system to be completely verified the final design must be fully operational in its designed environment. However the different tests allow for a progressive testing and evaluation scheme, it ensures that the development of the design is moving in the right direction based on the design requirements. By progressively testing a design, appropriate measures can be taken if the design is not meeting the requirements.

Evaluation

Once a system is finalised, it must be evaluated to ensure it not only complies with standards, any customer requirements and specifications. The customer 'wants' can be analysed against functional requirements, design requirements and design solutions (This can be done using a matrix with the different proposed models set against the top ranked requirements which are then given a weighted score. The higher rank the higher the weighted score (University of Calgary 2010). Before filling in the matrix a rating scale for the criteria must be established, such as 1 = low, 2 = medium, 3 = high, or 0 = little to 5 = great (American Society for Quality 2004). Whatever the scale, it must be consistent throughout evaluation and the highest number correlates to an important option of the design. The scaled score given to each criterion is multiplied by the weighted score of that requirement for each design then totalled at the end. The highest overall score is a design that should be considered as the most appropriate. If the customer disagrees the designers must return to the stage where they ranked the requirements and also determined the scaled scores (American Society for Quality 2004). This is one of many different types of evaluation criteria but is the method that will be used for this project.

Project Background

The project is currently entering its final stages with requirements, attributes, sub systems and proposed designs all being finalised. Currently the main frame of the bike is quite similar to a normal bike. Slight differences include the addition of a chair-like seat to keep the child secure on the bike and a harness to give them support whilst keeping them safe. The wheels are slightly wider to offer more stability and the addition of a mechanism similar to training wheels have been added (which can be removed if the child becomes competent enough) to the rear wheel to ensure stability. There is also a handle at the rear for the carer of the child to hold, push and steer the bike.

Customer attributes have being received, ranked and translated into design requirements with engineering characteristics to be measured. The influences and 'flows' have being mapped to see the relationships and interactions between the systems. The attributes were then cascaded down into tertiary attributes and their related systems (all of the afore mentioned can be seen in the Freedom Wheels final group report). All of these have been building to this stage for the system to be verified and evaluated.

Due to page limitations, only a section of the design will be verified and evaluated. This will be the steering mechanism and the safety harness used. Options for steering that have been looked at include a hydraulic system, a series of cables which when tightened on one side pull the wheel to that side, turning the bike and also a system which steers by applying brakes to either rear wheel to turn. Options for the harness include an across the waist type belt harness, a loop that goes around the chest (like in a dodgem car) and also a 5 point harness with over the shoulder supports and also across waist restraints (like a race car).

Case Study: Validation & Verification of Hearing Aids

Hearing aids are a tool that helps to improve the quality of life by assisting their users who are hearing impaired to hear others better. Current verification techniques focus on making the hearing aid gain match the given target but it does not evaluate if the hearing targets are appropriate in helping the user improve their speech perception or the actual benefit to the user (Mendel 2009).Validation is required to test the benefit to the user and can be done in three areas, treatment effectiveness, efficiency and effects. These outcomes can be determined through patient questionnaires and interviews and self-perceived improvement to gain a subjective perspective, or an objective one by analysing data and measurements. A series of tests have been developed that target a range of hearing loss thresholds and cover a range of situations and sounds (Mueller 2001). It is important to also have the subjective tests to insure the client (patient in this case) is satisfied with their aid and their requirements have been met.

Application to Freedom Wheels

Verification - Steering Tests

The first design requirement to be tested is the carer controlled steering located at the rear of the bike. It was a customer requirement that the steering of the bike be the responsibility of the carer who was assisting the child on their bike.

The following tests can be performed to ensure the steering is suitable for the customer and their requirements. They are a combination of proof-of-concepts with procedures, calculations and some tests that can't be performed until the system prototyping stage.

These tests come under the attributes A4.0 Cost efficient and A6.0 Controls at rear (For all attribute ID's see Freedom Wheels group final report).

Attribute ID: A6.2.1* Minimal turning circle

Test Person: Manufacturer of bicycle (TADACT)

Pass/fail criteria: The radius of the turning circle must be less than 5 metres

Proof-of-concept procedure

1. Theoretical values can be calculated using the following approximation where x is the length of the wheel base and theta is the angle that the handle bars can turn to when fully locked to one side (Kroll 2012). As the wheel base is unlikely to change, theta is the variable here.

$$Turning\ Circle = 1 + \frac{x}{\sin(\theta)}$$

2. Physical testing of the design once prototyped – set steering fully locked to one side
3. Push bike with locked steering until complete 180^{o} turn is completed
4. Measure the distance from the starting point to the finish point

Attribute ID: A6.1.1 Minimal force to maneuverer

Test Person: Technician setup

Pass/Fail criteria: force required is less than 50N

Proof-of-concept procedure

Using strain gauges to measure the force required which need to be set up by a technician.

1. Testing can be performed by anyone once set up
2. Apply force to move bicycle wheel from neutral centre line to 30^{o} away
3. Measure and record the force required

Attribute ID: A4.1.6 Steering mechanism is less than $200

Pass/fail criteria: less than $200

Verification - Restraining Device Tests

These are tests that ensure the safety of the child is met though the proper restraining of their body as well as attaching their feet to the pedals. This comes under another requirement of wanting the child to exercise by having their feet moved by pedals but will be tested under retraining devices due to the similar nature of the harness and straps.

These are tests for the primary attribute A7.0 Effective Harness.

Attribute ID: A7.1.1 Minimal movement possible from harness

Test Person: TADACT

Pass/fail criteria: rider cannot move more than 30 cm from original position

If they can fall out, automatic fail

Proof-Of-Concept Procedure

1. Restrain person in the harness
2. Measure how far person can move from original position

Attribute ID: A7.1.2 harness is simple design (also refers to ease of access attribute)

Test Person: TADACT

Pass/fail criteria: time taken to restrain child is under 20 seconds

Proof-Of-Concept Procedure

1. Start clock
2. Seat child
3. Restrain child
4. Stop clock

As stated before this is only a subset of the attributes to be verified. Ideally the tests are designed to be carried out by a TADACT member where possible as this reduces costs of design as no technician or expert would need to be hired.

Evaluation

Due to the different design solutions to particular aspects of the bike, such as those verified above, these will be evaluated separately, as well as the whole bicycle. It must be noted that these evaluations have been made with educated assumptions but as no testing could be performed some outcomes are difficult to be certain about.

Table 1. Evaluation Matrix of Different Steering Options

SCALE 5 - Exceeds compliance 3 - Compliant 1 - Some commpliance 0 - Non-compliant	Weighting		Hydraulic		Cables		Brakes	
	Rank	Weighting	Compliance	Weighted Value	Compliance	Weighted Value	Compliance	Weighted Value
Appealing (look normal)	6	2	3	6	3	6	3	6
Cost efficient	2	6	0	0	3	18	3	18
Ease of access	6	2	3	6	3	6	3	6
Carer controlled steering(rear)	3	5	3	15	3	15	3	15
				27		45		45

Table 2. Evaluation Matrix of Different Harness Options

SCALE 5 - Exceeds compliance 3 - Compliant 1 - Some commpliance 0 - Non-compliant	Weighting		Waist Belt		Chest Loop		Full harness	
	Rank	Weighting	Compliance	Weighted Value	Compliance	Weighted Value	Compliance	Weighted Value
Appealing (look normal)	6	2	5	10	3	6	1	2
Cost efficient	2	6	5	30	5	30	1	6
Ease of access	6	2	3	6	5	10	1	2
Withstraining device	3	5	3	15	5	25	5	25
Adjustable seat height	5	3	3	9	3	9	1	3
				70		80		38

Table 3. Evaluation Matrix of Different Bicycle Designs

SCALE 5 - Exceeds compliance 3 - Compliant 1 - Some commpliance 0 - Non-compliant	Weighting		Proposed Design		Normal Bike		Current Bike	
	Rank	Weighting	Compliance	Weighted Value	Compliance	Weighted Value	Compliance	Weighted Value
Robust stabilising system	1	7	5	35	1	7	5	35
Wide wheel base	4	4	5	20	1	4	5	20
Appealing (look normal)	6	2	3	6	5	10	1	2
Cost efficient	2	6	3	18	5	30	3	18
Ease of access	6	2	3	6	5	10	3	6
Carer controlled steering(rear)	3	5	5	25	0	0	0	0
Pedal Straps	6	2	5	10	1	2	5	10
Withstraining device	3	5	5	25	0	0	5	25
Terrain difficulty	7	1	3	3	5	5	3	3
Moving pedals	4	4	5	20	5	20	5	20
Adjustable seat height	5	3	3	9	3	9	3	9
				177		97		148

Discussion

By regarding the tables above of the different evaluations performed Table 1 can be seen to have a tie between the cables and the braking steering solutions. The hydraulic solution scored the lowest due to its high cost. This also resulted in this system failing an earlier test of costing less than $200 as the design, purchasing and installation of such a device is quite expensive. The cables and steering by braking scored equally in all of the requirements. The testing process would be useful here to determine the more appropriate solution. It is suggested that the steering by braking may have the smaller turning circle as well as require less force due to its set up. It must be considered that this solution will affect the chassis and control subsystems (see Freedom Wheels group project – Flow Block Diagram) which must be taken into consideration as this may make it an inappropriate solution. Also of concern would be the quality of tyres as steering by braking would cause tyres to slip on the surface as they made the turn, which would then degrade the tyres faster compared to the cable method. The whole system needs to be considered when such decisions are made. While both designs are projected to come in under the set budget of $200, perhaps the cheaper design may be a more attractive option as this reduces the overall cost of the bike. The cheapest solution cannot be determined at this point due to unknown factors such as the final layout of the bicycle design. At this stage the cables method appears to be the cheaper method due to the lower cost of materials. The testing of prototypes would be helpful in ultimately determining which is most appropriate.

Table 2 evaluates the different harnesses suggested for the bicycle. As the children who ride the bike have varying disabilities and degrees of strength, the required harness may be subject to change. The seat and harness can easily be alternated as they all attach to the seat post in the same manner. For this example it was assumed the child had limited upper body strength and needed support. With this in mind it can be seen that the full upper body harness and the chest loop scored high as they restrain the body. The 5 point harness was however the most expensive, and scored low on this highly weighted requirement. It also didn’t meet the customer requirement that the bike look as normal as possible. The waist belt scored quite high on most requirements due to its cheap material use and discreetness. The chest loop outscored the waist belt in one major area which was the actual restraint of the child. The waist belt did not provide enough upper body support for which the child in this instance was a weighty requirement. This would also be made evident in the testing processes for the safety harness.

The final evaluation performed was of the bike as a whole system. For this evaluation the proposed design was considered against a normal bike and the current adapted bike used. The normal bike was used to see how the modifications made it possible for disabled children to use it. The current design (which can be seen in an image in Appendix 1) was also used to see if this new design was able to outperform the old. The normal bike scored highly in areas of appearance, as the children want a normal looking bike to ride, as well as low cost due to no modifications and its ability to handle all terrains. It fell away in the areas of requirement specific to the disabled children such as the need for a harness and carer controlled steering. The old design scored quite highly on many requirements in regards to the safety and stability of the system. It lost points on its appearance as the modifications are not subtle and also on the rear steering as this bike had its steering located at the front. This was one of the major requirements as currently all designs have the carer steering at the front of the bike and one of the major challenges for this project was to change this to the rear. The proposed design ended up scoring the highest total to the high compliance of the rear steering, restraining device (determined earlier) and the stability of the system.

Conclusions

From the above mentioned tests and evaluations, it was determined that the best design for the Freedom Wheels client was the carer controlled rear steering bike with a chest loop harness. Further testing is required to determine the best method of implementing the steering though the tests are already determined; all that is left is to create an actual design. Prototyping and a series of tests will help to ensure that all requirements are met, including those not mentioned in this report and the customer receives a safe, stable and satisfactory product.

Bibliography

Blanchard, B.S., W.J. Fabrycky, *Systems Engineering and Analysis*, Fifth ed. Pearson, New Jersey, 2011

Browne, C., *ENGN2225 OC – Validation,* YouTube, last updated 28 April 2013, <https://www.youtube.com/watch?v=yruHXbsZRzk&feature=share&list=PL2hygCecjFiXEDTXwBOgWlAFVZL06gnSA> viewed 19 April 2013.

Browne, C., *ENGN2225 OC – Evaluation,* YouTube, last updated 6 May 2013, <https://www.youtube.com/watch?v=4CglMoAfhSI&feature=share&list=PL2hygCecjFiXEDTXwBOgWlAFVZL06gnSA> viewed 19 April 2013.

Decision Matrix, American Society for Quality, last updated 2004, <http://asq.org/learn-about-quality/decision-making-tools/overview/decision-matrix.html> ,viewed 23 April 2014.

Evaluation Matrices, University of Calgary, lasted updated 2010, <http://people.ucalgary.ca/~design/engg251/First%20Year%20Files/eval_matrices.pdf > viewed 23 April 2014.

Kroll, J., *How to calculate the turning radius,* eHow, last updated 2012, < http://www.ehow.com/how_7225784_calculate-turning-circle.html > viewed 6 May 2014.

Hidlebrand, J.,*Push on for a new sponsor to get disabled kids on their bikes,* The Daily Telegraph, < http://www.dailytelegraph.com.au/push-on-for-a-new-sponsor-to-get-disabled-kids-on-their-bikes/story-e6freuy9-1225983258181> , viewed 7 May 2014.

Mendel, L., *Subjective and Objective Measures of Hearing Aid Outcome,* Audiology Online, last updated 9 February 2009, <http://www.audiologyonline.com/articles/subjective-and-objective-measures-hearing-891>, viewed 23 April 2014.

Mueller, H., (2001). Speech audiometry and hearing aid fittings: Going steady or casual acquaintances. *The Hearing Journal, 54*, 19-20, 24-26, 28.

What We Do, Technical Aid to the Disabled ACT, last updated 2011, <http://www.technicalaidact.org.au/what-we-do/.html> viewed 23 April 2014.

Appendix A.

Current bicycle design for disabled children

Source: http://www.dailytelegraph.com.au/push-on-for-a-new-sponsor-to-get-disabled-kids-on-their-bikes/story-e6freuy9-1225983258181

Peer Review Critique

I did not find my peer reviews very useful. Admittedly I only provided them with roughly 800 words so they did not have a complete report to critique (never mind one of my reports I had to peer review only had 100 words!). One person pointed out that I was interchanging verification and validation, which both mean the testing stages of the design but I tried to change this to mainly use verification to avoid confusion. My second peer reviewer was slightly more callous, but never very constructive. Telling me I clearly need to watch the online classrooms again is an example. This person also did not like my case study of hearing aids, a subject close to my heart. They called it irrelevant and say that no information on validation and evaluation is provided. They also gave me a 'helpful' link to find a better case study. The link was to a Google search page where the search bar had 'case study on verification and validation'. This contradicted what the other peer reviewer said who liked my case study and even suggested maybe I cut down the text in that section to make room for other parts.

It was also suggested that I go back and test all of my tertiary attributes in the attributes cascade, which suggests to me they don't quite understand the length of testing that would require, which would not fit in such a short report, unlike what Chris suggested to me that I take a segment of my attributes table which was what I did. I did take their suggestion of removing my pairwise table as it did take up space which I needed for other things. My report contained a full theory section in the draft but this person deemed that unsatisfactory as I hadn't provided enough content. I think they may have assumed that everything I had written was incomplete and not actually seen my theory (which the other peer reviewer said was outstanding).

One reviewer states my bibliography is outstanding, just needed to be in alphabetical order which was fair as I hadn't done that yet. The other said that the only good thing was I had at least used the proper style of referencing. They couldn't see a clear use of the articles in the paper, despite the fact that every single one had at least one in text reference.

It may be that I don't handle criticisms well but I found that the second peer review in particular was not very helpful or constructive, and made me feel bad about what I had written so far.