Design Project 2 Section B: Product Visualisation and Analysis

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Abstract

The aim of this project is to address to the healthcare needs of remote communities in Sub-Saharan Africa. This is done by providing an all-terrain bicycle ambulance that is able to transfer incapacitated patients safely and comfortably to the nearest medical centre, function as a mobile clinic for communities and store critical medication such as vaccines in a refrigerated environment. Initially this report summarises the combined work done by groups one and two in previous stages of this project; the transition from the design brief to a final concept design. Within this section research is carried out into the proposed problem to generate a problem statement and design specification, summarising previous concept generation and down selection processes. Finally, final concepts are combined using an MCDA down selection technique to create a combined concept to carry forward. The bulk of this report focuses on design development, embodiment and analysis. The combined concept is broken down into different subsystems. Potential solutions that fulfill the required subsystem function are proposed, compared, analysed and finally implemented. The new developed concept is modelled through use of CAD, accompanied by relevant technical drawings and assembly procedures. To ensure the design is feasible both structurally and economically, proving calculations pertaining to material selection and manufacturing costs are carried out. Finally, numerical analysis is completed using MATLAB. By modelling a vaccine storage unit the effectiveness of the unit is determined. This aids in optimising storage volume whilst maintaining the required level of insulation. The output of this project is a feasible product that will serve to increase the availability of medical services to rural communities in Sub-Saharan Africa.

Contents

Figures

1 Introduction and Specification

1.1 Introduction

The bicycle as we know it was invented in 1817, [2] whilst its appearance may have changed over its lifetime its function has not. The bicycle is a cheap and sustainable method of transport and is a critical method of transport for millions of people all over the world, particularly in developing countries due how cheap they are.

Africa is the second largest continent in the world with a population of 1.3 billion [3] and is rapidly growing. Healthcare has always been a weak spot for this continent with less than half of the population of Africa having access to modern healthcare. [4] Figure 1 shows all known hospital locations in Sub-Saharan Africa. Whilst certain areas do display areas of impressive hospital density such as Nigeria or the Democratic Republic of Congo, there are vast sections demonstrating that hospital access in Sub-Saharan Africa is unacceptable. according to the World Economic Forum nearly 30% of the population of this part of the world live over a 2-hour drive from the nearest hospital.[5]

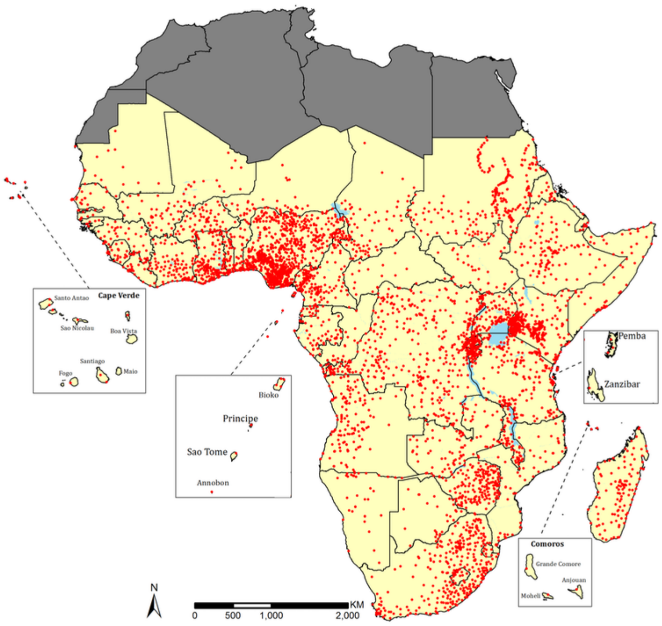


Figure 1: Hospital Locations in Sub-Saharan Africa

From this initial research into the problem and potential solution a problem statement was derived that provided a basis from which to work on the design process. The problem statement is as follows:

"There is a lack of access to services for patients in rural and inaccessible locations in Sub-Saharan Africa. Paramedics operating out of medical facilities require an affordable, all terrain, bicycle ambulance that can be attached to most standard frame bicycles. The design must transport patients, medical equipment and supplies, including vaccines, over a distance of at least 5 miles."

In Phase A large amounts of research was conducted into the problem constraints. This went beyond what had been given as part of the design brief. [6] The research was split into three major sections:

- The different environments and terrains the design would have to navigate.
  - Paramedic bicycles already in existence and required paramedical equipment.
  - Functions the design has to fulfill and the problems these present

This newfound knowledge allowed for design specifications to be constructed. The design specifications between the two groups were very similar and have been compiled into a final specification as seen in Table 1.

The priorities are designated from low to high (L-H) in importance and a demand (D) is means that this point must be satisfied in the final design.

1.2 Specification

Table 1: Final Specification

Category	Reference	Description	Priority
Safety	1.01	Must protect the patient from environmental factors, such as rain.	D
	1.02	The patient must be distanced from the paramedic to minimise risk of contamination.	D
	1.03	The patient must be protected from rough terrain.	D
	1.04	Personal hygiene features must be included, such as hand-sanitizer and PPE storage.	D
Storage	2.01	Must be able to safely store vaccines at sub-zero temperatures for 24 hours.	D
	2.02	Must have the capacity to store mandatory medical supplies for treatment of incapacitated patients.	D
	2.03	Must have safe storage space for used and unused sharp instruments as well as hazardous waste material.	D
	2.04	Must be able to carry the required medical supplies in a high enough volume to function as an ad hoc clinic.	D
Comfort	3.01	Patient comfort in bed, beyond the required comfort for safety.	M
	3.02	Driver should have comfortable saddle and sufficient leg space to pedal comfortably.	H
Function	4.01	Must be able to transfer patient in and out of the ambulance with a minimum of 2 people	D
	4.02	The ambulance must fully function for at least 5 miles on rough terrain.	D
	4.03	The final design needs to be agile and slender to reach inaccessible locations.	H
Manufacturing	5.01	52'000 units need to be manufactured to match the ambulance density of London. [7]	D
	5.02	Product must be manufactured in Sub-Saharan Africa to support the local economies.	D
Durability	6.01	Design must be able to withstand harsh environments, between temperatures of -24°C and 51.3°C, wind speeds up too 30mph and road conditions including but not limited too mud, loose surfaces and potholes.	D
Maintenance	7.01	All maintenance can be carried out with spanners, sockets and cross-head screwdrivers.	H
Economic Factors	8.01	Minimise cost per unit.	M
	8.02	Unit must cost no more than £1000.	D
	8.03	Minimise maintenance costs.	M
Sustainability	9.01	Sustainable manufacturing techniques	L
	9.02	Product should be recyclable when it reaches the end of its life cycle	M
Accessibility	10.1	Product must be accessible by people of all ages, disabilities and injuries.	D

Two categories have been discarded: Aesthetics and Form. This decision was made as they both contributed little to the design of the ambulance in Phase A and were allocated the lowest priorities in their respective down selecting process.

2 Conceptual Design Process

2.1 Conclusions Drawn From Further Research into Specification

With the new combined specification further research was conducted into each category. What follows are the key conclusions that were arrived at as a result of the research.

For safety purposes in the event of abrupt crash or stop and to maximize patient-paramedic separation as to minimize the potential spread of antigens, it was decided that the patient should be facing forwards (their head being toward the read of the trailer). The patient requires access to water. The trailer will require a suspension system that can cope with very rough surfaces where there are no roads and large potholes for when roads are not well maintained. Ambulance must carry standard emergency medical response kit; this can be summarized as the contents and volume of a St Johns First Aid kit.

The stretcher will be fabric-based with two wooden rods spanning the length of the stretcher acting as handles. This design allows for a high strength to weight ratio. The floor of the unit will need to not only be able to function as a table for an ad-hoc clinic but will also incline to 30°as is the Semi-Fowler's position for women in labour and to promote lung expansion.[8] The ambulance will transport vaccines in cooler boxes in the storage component located on the unit. Waste can be deposited in a bin located in one of the aforementioned storage compartments.

The ambulance suspension and frame will be made from an aluminium alloy. This was decided due to its high strength and excellent weld-ability. All aluminium alloys have excellent corrosion resistance, ideal for the for the monsoon environment of Equatorial West and Central Africa. [9] Compared to mild steel, it is superior in both resistance to weathering and its strength to weight ratio ratio. [10] The flooring of the unit will be made from closed-cell foam with an elevated section around the head and neck area. The saddle will also have a base of closed-cell foam with a leather surface. Closed-cell foams were chosen over their open-cell counter part due to its resilience to moisture. [11]

While cost is something to be optimized, the manufacturing price per unit will be capped at £1000. With regards to assembly and maintenance, the unit will be manufactured as a flat pack so the unit can then be assembled using only hand tools by maintenance teams. Such a design will reduce production and maintenance costs. 52'000 flat pack units will be manufactured as to match the ambulance per capita of London.[7]

2.2 Concept Generation

Concept generation is a vital part of the design process. It provides strong foundations from which a viable solution can be built. Concepts allow for an expansion in the range of ideas beyond the current scope. With this in mind rather than developing concepts for the trailer as a whole, multiple concepts were modelled for each major sub system. Using mind maps, morphological analysis and other creative techniques, concepts were generated to specifically satisfy individual functional requirements. Each down selected concept then carried forward to the final design.

Group one deviated from this routine. It was decided that to increase the relevance and accuracy of generated concepts, the trailer location would be decided prior to concept generation. Trailer location was decided using a simple pro con ranking method. As a result all of group one's sub-system concepts were build around the trailer being to the rear of the bike. This allowed for the generation of more relevant and in depth sub-system concepts and would subsequently enhance the degree of design specification satisfaction.

2.3 Down Selection and Final Concepts

Having developed a large array of concepts both groups used a Multi-Criteria Decision Analysis (MCDA) down-selection method to arrive at out final concepts.[12] Having run all proposed designs through the MCDA algorithm and produced weighted scores for each concept, the optimum components were extracted, combined and refined to produce the final designs. The weightings of comparative parameters are decided through the use of a pairwise comparison table. Figures 2 and 3 show both the final concepts from Groups 1 and 2 respectively.

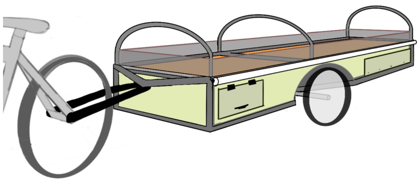


Figure 2: Final Concept - Group 1

Figure 3: Final Concept - Group 2

The final concept for Group 1 in phase A is a flatbed stretcher trailer attached to the rear of the bike. It has four storage compartments with one at each of the corners of the unit. The design has fabric walls to hold the patient in with an arching frame to support a light cover which would shelter the patient. This cover is designed to roll out over the patient and protect from weather extremes.

the final concept for Group 2 is a moving stretcher bed with an ability to recline. The angle of elevation will be 30°. This concept is attached to the side of the bicycle with a single wheel for support. There is a large storage compartment at the front of the unit on the outward facing side. There are two transparent support structures either side of the patient, these will hold a light cover to shelter the patient. Similarly to the concept from Group 1, this cover will roll out to protect the patient from the rain.

2.4 Starting Concept

Fundamentally the two concepts presented in figures 2 and 3 are very different. An MCDA method was used to determine which design will be carried forward.[1] It concluded that the final concept from Group 1 will be carried forward. The final concept from Group 2 is used to combine features for design embodiment, in order to enhance the the degree of specification satisfaction of group 1's concept, such as the facility for an inclined bed. Figures 4, 5 and 6 show the final design's chassis design, frame and cover.

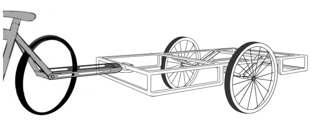


Figure 4: Final Concept Chassis

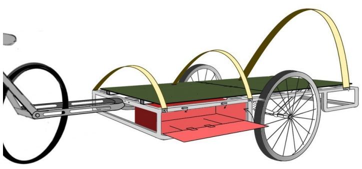


Figure 5: Frame and Storage

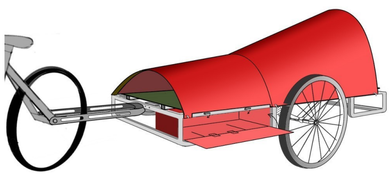


Figure 6: Full Final Concept

[1]The full MCDA table of results is in section 8.1 of the appendix.

3 Concept Development and Design Embodiment

Sections 1 and 2 summarise the work completed in Phase A and output a combined concept to be carried forward. Further sections will look at concept development, focusing on transitioning from simple 3D sketches to a feasible product that can be developed, analysed and delivered.

3.1 Chassis Frame

Material selection for the frame and other critical components was conducted through the use of CES EduPack software. [1] The required characteristics were identified. The chosen material must be able to operate at -24°C — 51.3°C, it must have excellent weather and corrosion resistance and withstand an applied load of 115g. From this, EduPack revealed a choice of 3 final materials. The parameters are taken from specification requirements; the working temperature must be at least the highest temperature recorded in the deployment area. [13] From this, down selection considered minimising the cost to weight ratio. Through this, Aluminium 6061 Alloy was chosen due to an excellent specific strength and ease of manufacture and availability.

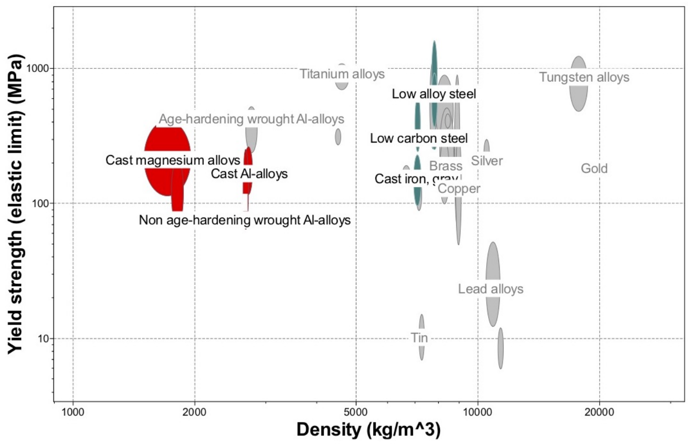


Figure 7: CES EduPack Material Selection [1]

3.2 Suspension System

Rough surfaces and potholes are a serious threat to user comfort and safety, especially for those with spinal injuries. For these reasons a spring-based suspension system will be employed. The three main spring configurations being considered are, as shown in figures 8, 9, 10, a vertical damped spring shock absorber (VDSSA), a leaf spring suspension system and an angled damped spring shock absorber (ADSSA).

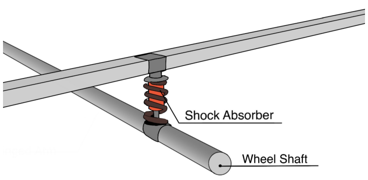


Figure 8: Vertical Damped Spring Shock Absorber

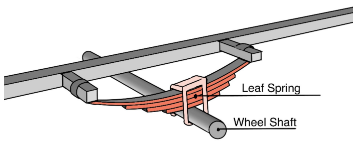


Figure 9: Leaf Spring Shock Absorber

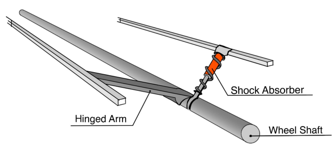


Figure 10: Angled Damped Spring Shock Absorber

The VDSSA, while offering an effective solution for the dissipation of vertical momentum has no protection against horizontal impact forces. This is a crucial design flaw which could compromise the patients' safety. Leaf spring suspension has similar issues to the VDSSA - it is only designed to absorb vertical shocks. Over time, frequent horizontal shocks will cause heavy wear on joints between the suspension and the frame. [14] The composition of the system entails multiple layers of steel sheets making it excessively heavy in the context of this application. The ADSSA is light and offers absorption for both horizontal and vertical shocks by having an angled shock absorber. This is chosen system to be carried forward to the final concept.

3.3 Storage

The storage will be comprised of a modular system inspired by the designs used in London ambulances. The storage units can be inserted from either side of the vehicle, allowing for 4 separate module compartments. The container will slide out of the frame so they can be removed when not required as to minimise the weight. A hinged door is locked into place using simple clips and therefore secured from opening. This system will function through use of a rail below the box. Figure 11 visualises this design.

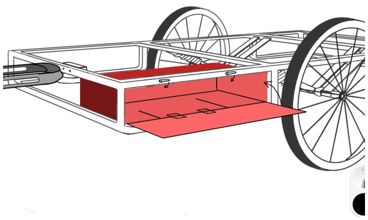


Figure 11: Front Left Storage Compartment

3.4 Bike-Trailer Hitch

A further key aspect of the design is the attachment method used to connect the trailer and the bicycle. The research previously carried out in phase A, reveals the reasoning behind the design decisions that have been made: an attachment to the rear axle of the bicycle is the most secure due to a combination of low centre of gravity and strength. Although requiring some assembly, a rear axle mounting mechanism allows for far greater loading and stability. Additionally by using a low mounting, rather than a seat post mount, the maximum rolling moment the trailer can exert onto the bicycle is reduced.

To down select the initial system designs, key requirements are used. Amongst them, degrees of freedom include the ability to roll, pitch and yaw relative to the bicycle. These are possible with ball and socket joint, a chariot hitch and any mechanism designed to have 3 separate rotating components. These concepts are shown below:

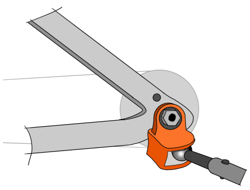


Figure 12: Chariot Hitch

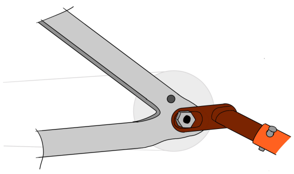


Figure 13: Simple Linear Socket Joint

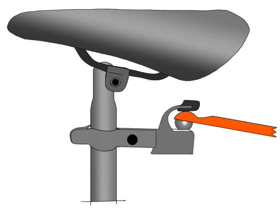


Figure 14: Ball and Socket Joint, Attached to Saddle Post

Through careful consideration of the specification, a chariot style hitch was chosen for this purpose. While relatively simple mechanically, this joint allows a large degree of freedom whilst allowing the paramedics to detach the trailer with simplicity making it a favourable solution for use as a trailer ambulance and ad-hoc medical centre. The linear joint does not offer the degrees of freedom required and the ball and socket joint increases the rolling moment produced by a rolling trailer.

3.5 Stretcher and Floor

From the design brief, the bicycle ambulance must function as a transporter of patients and an ad-hoc medical clinic. This second requirement adds the complexities of a free standing trailer with a flat work surface. Additionally, research in phase A revealed the benefits of having a bed inclined 30°[8], helping to improve blood circulation in patients.

The chosen solution combines a rail system with a hinged back support. Tracks run the length of the trailer base. Rails that connect to the tracks are attached to the non reclining section of the bed and continue the entire length of the bed. Through this, the stretcher can sit securely in the trailer without hindering the reclining hinge system. For stability the stretcher is locked into place with rubber end caps. For the reclining function in Figure, 16 extending supports are used to hold upper body section of the bed up. For support while use as a work surface, the rail extension is supported by a fold out leg as shown in Figure 15.

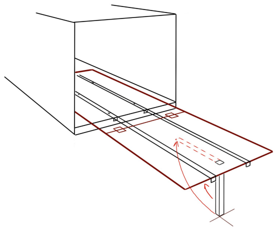


Figure 15: Bed Extended as Flat Work Surface

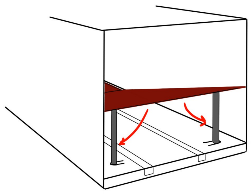


Figure 16: Reclining Mechanism

Material selection for this subsystem utilises the same decision-making as that of the frame. Aluminium box sections and rails will be used for the stretcher support and aluminium sheet will be used for the backing. These are lightweight and stiff materials which allow the system to function as designed with limited deflection under load.

3.6 Cover

Below are the sub-system concepts for the cover arrangement:

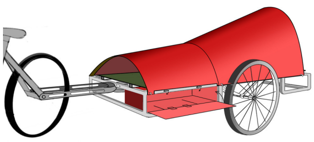


Figure 17: Cover Concept 1

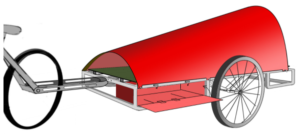


Figure 18: Cover Concept 2

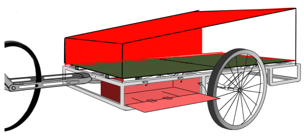


Figure 19: Cover Concept 3

Continuing from the phase A designs of both groups, the cover design is a combination of the best features from the earlier designs. These will make use of the frame system to guide the cover as demonstrated in both Figures 2 and 3 from the initial concepts. Developing further, design for manufacture is a key issue that is considered. Through further down-selection using the MCDA matrix, cover concept 3, Figure 19 is chosen as the most suitable design. With the most simple structure, manufacture and assembly for this option can be completed with minimum cost. The waterproof polyester fabric that would be used is pinned only on top. It also allowed for the cover to be partially opened, both for more airflow and comfort for the patient, something which the other concepts in Figures 17 and 18 do not allow.

4 Detailed Design

4.1 Design Definition

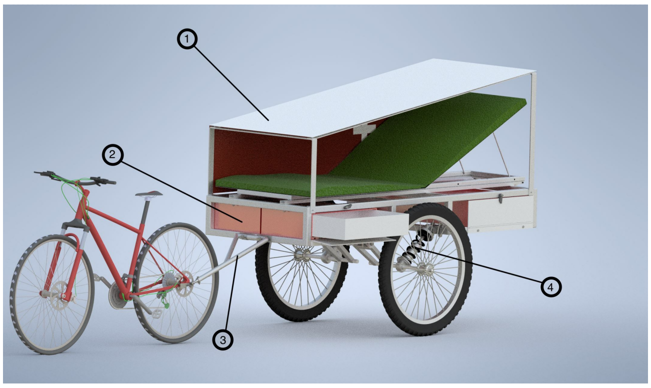


Figure 20: Final Design Annotated Render.

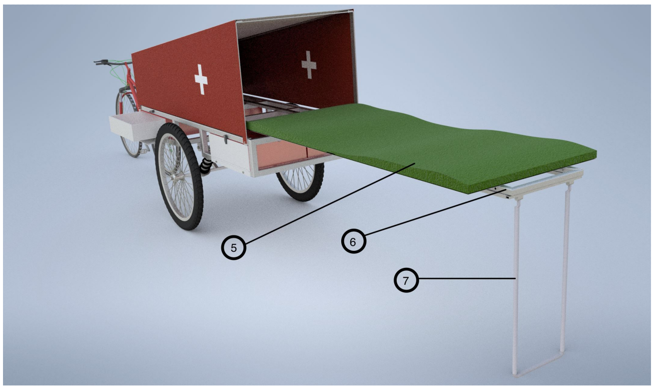


Figure 21: Final Render Showing Stretcher Use.

4.1.1 Key Components

1. Cover assembly, comprising of waterproof and UV resistant polyester. The key changes to this sub-system from the initial design include the changing of the shape, to a more manufacturable rectangular net, and the ability to fold away the sides and front for better airflow.

2. Storage assembly, as shown in the initial design, the storage containers can slide out of the frame, with lids and turning locks to ensure these are held in place when in motion.

3. Hitch assembly, as described in 3.4, employs a chariot hitch connection. Improvements have been made through the addition of truss structure for increased strength.

4. Suspension assembly, making use of ready manufactured shock-absorbers and an aluminium hinge, this corresponds directly to the sub section down selection completed in section 3.2.

5. Stretcher padding, as an improvement on the initial design, padding has been added to the stretcher in order to improve patient comfort.

6. The stretcher assembly is strengthened through the use of an aluminium box section and attaches as described in Section 3.5. The reclining mechanism, as shown in , has been changed to use a simple aluminium rod to support the back of the stretcher when at the desired incline.

7. As in the concept design, the stretcher is supported by aluminium tube legs that allow patients to be placed onto the surface and allow the surface to act as a make-shift table when in use as a medical centre.

4.2 General Assembly

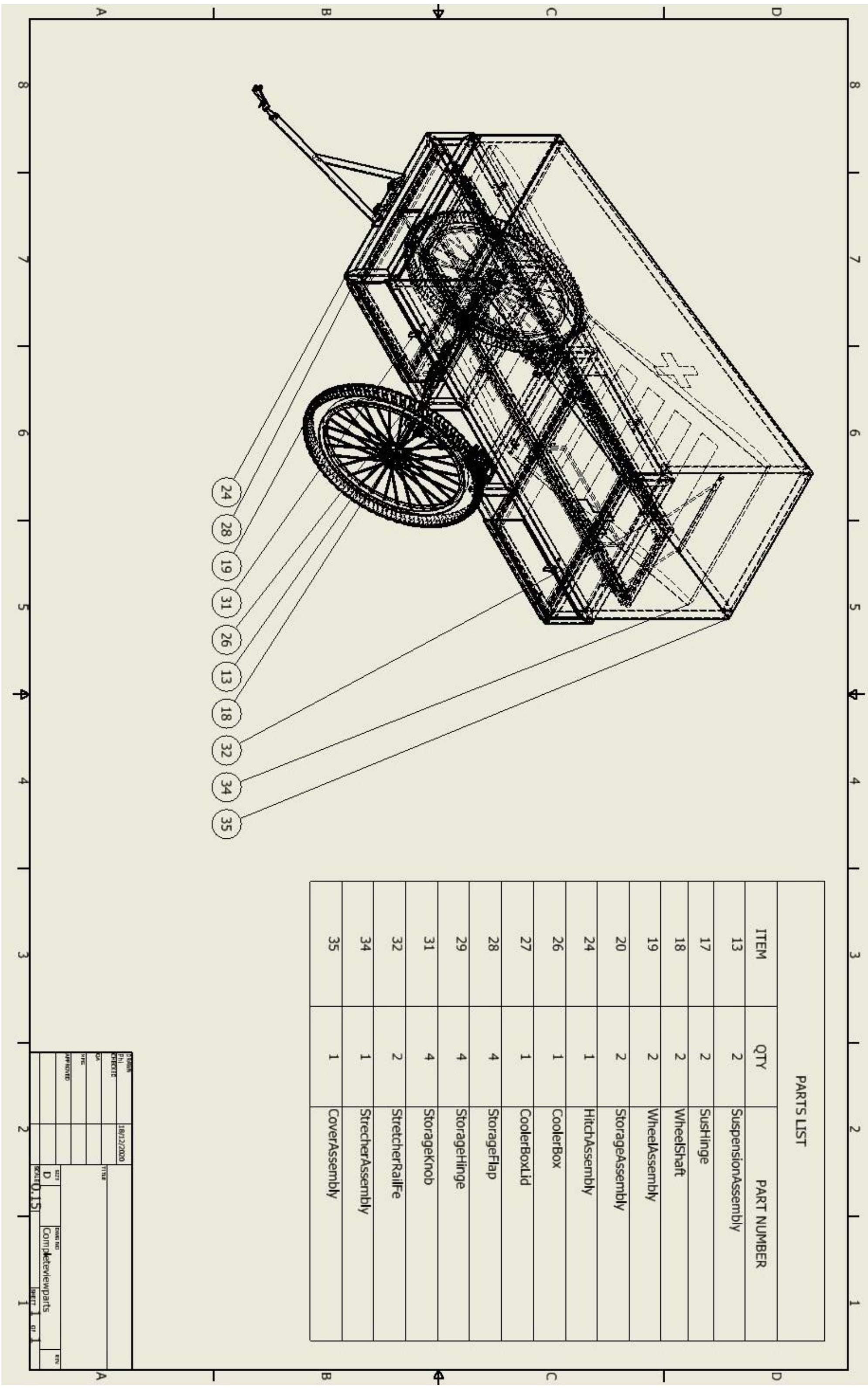


Figure 22: Full Assembly Drawing [2]

[2]Full bill of materials included in appendix.

4.3 Orthographic Projection

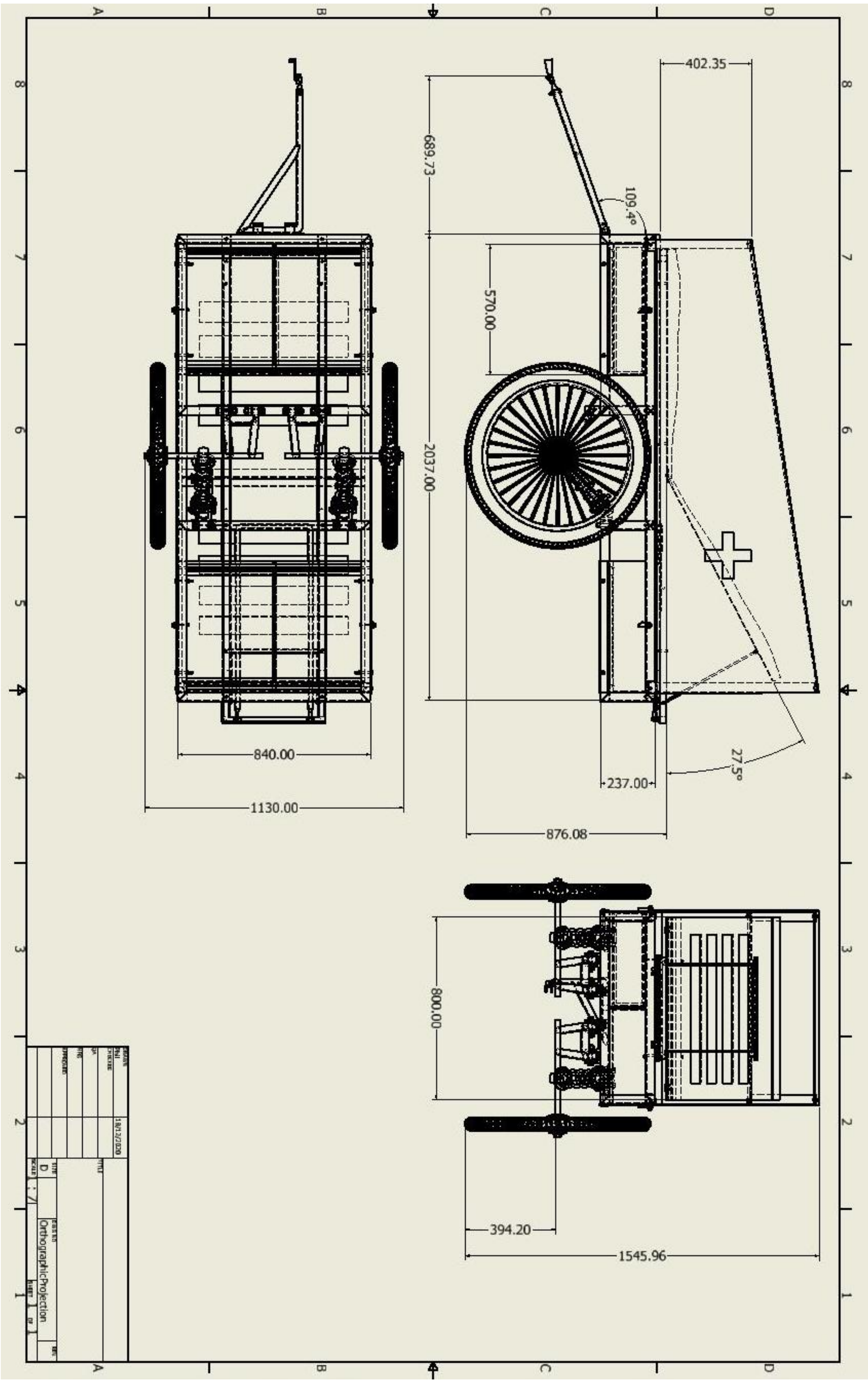


Figure 23: Orthographic Projection

4.4 System Assembly

4.4.1 Manufacturing Methods

Making use of South Africa's developing infrastructure for manufacturing, the product will be manufactured to a flat-pack style stage in a developed area and then shipped to the deployment sites where it can be assembled with basic tools. The use of an aluminium frame structure means that the manufacturing process is significantly more difficult. [15] Tungsten inert gas (TIG) welding will be employed as the key manufacturing method for the frame, hitch and suspension assemblies. The resulting fabricated components will be packaged within a container slightly larger than the frame assembly: 2100x250x850mm. Inside the packaging, the frame will be used as a make-shift perimeter for the rest of the components

The suspension shock absorber and wheels will be purchased from wholesale retailers and combined with the welded components and other parts in the container, along with all the required fixings. These parts will be packaged in small cardboard boxes labelled for each sub assembly and with basic instructions in the form of assembly drawings and exploded views. By designing for manufacture, this product will be assembled from the flat-pack stage with only the use of basic tools. All joints and connections, that are not welded in the first stage of manufacture, will be made using spanners, sockets and cross-head screwdrivers. This allows small rural areas to complete the manufacture of the product themselves allowing the NGO responsible to drive costs down and therefore expand the availability of this product a wider area.

Other manufacturable components include the cast aluminium and steel components used in conjunction with the frame and suspension assemblies. For aluminium components, the die casting process will be employed for large scale production of this product. Partnering with large manufacturers in South Africa [16], the NGO can have these components manufactured and the flat-pack assembled in the same city. This will reduce the secondary costs involved in shipping.

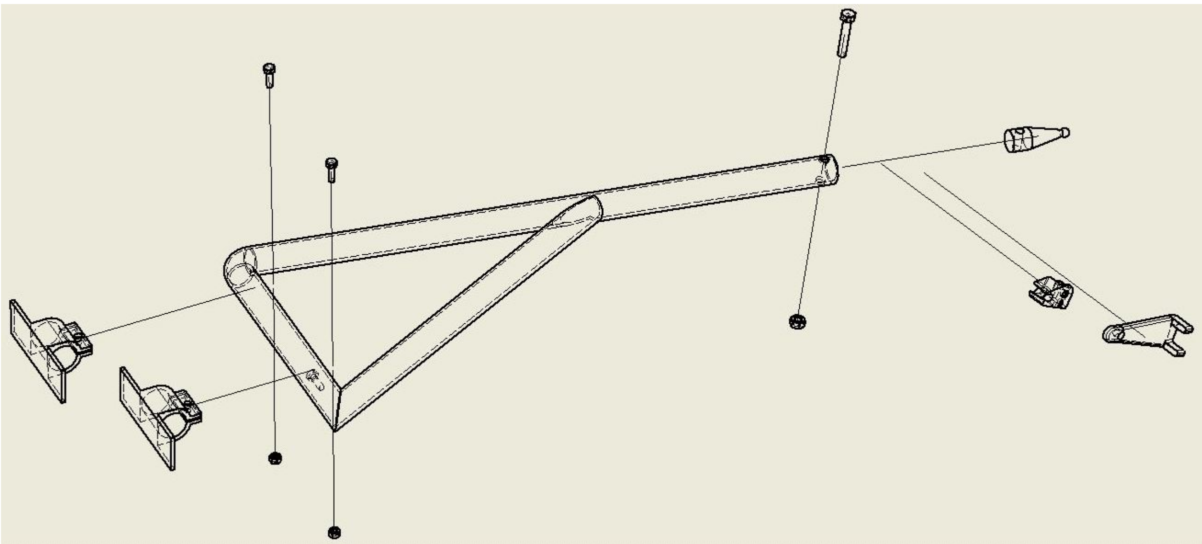


Figure 24: Hitch Mechanism Exploded View

As seen above in Figure 24 the entire system assembly instructions will be shown through the use of exploded views, complete with a parts list and numbering. This will allow the product to be completed using the basic tools included in the flat pack package. This figure shows how the hitch is attached to the frame via tightening holders and the chariot hitch assembled using the 3 main cast components.

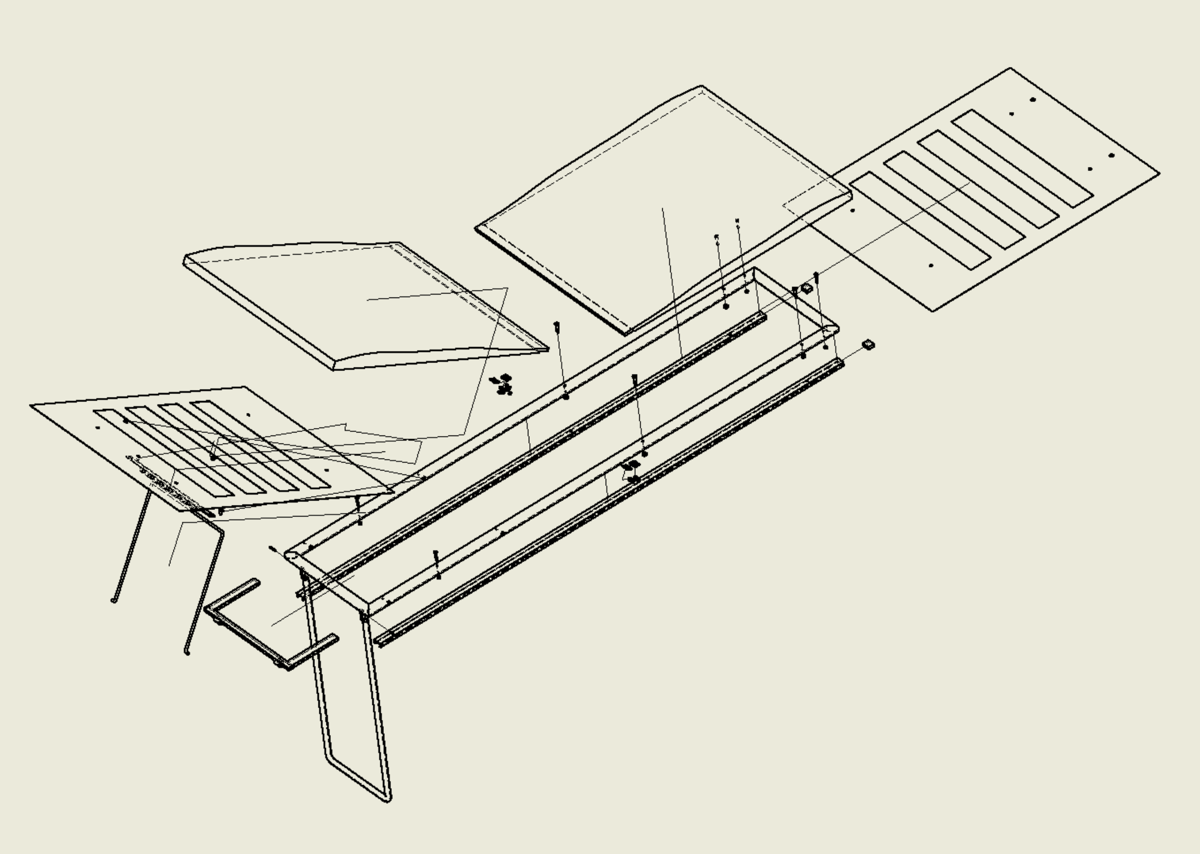


Figure 25: Stretcher Assembly Exploded View

The stretcher assembly exploded view in Figure 25 demonstrates the combining of components through the use of simple bolted connections. Although complex, the use of an exploded view will allow workers to build the assemblies that are required in this product with ease.

4.4.2 Complete Installation Sequence

1. Gathering of raw material at chosen workshop based in developed area and completion of all welding required in frame, hitch, stretcher and suspension sub assemblies. This will be packaged and shipped with tools to deployment location as a flat pack.

2. Assembly begins with attachment of suspension system to frame. Requiring only bolted connections with the pre-fabricated components, this can be completed with included tools: sockets, spanners and screwdrivers. Importantly this increases the repairability of the product.

3. The hitch mechanism will be constructed using the exploded view for reference. This is attached to the assembly. The wheel set will then be connected to the suspension and stabilised with a support to allow further assembly.

4. Separately, the stretcher, cover and storage assemblies must be constructed using the exploded views for reference.

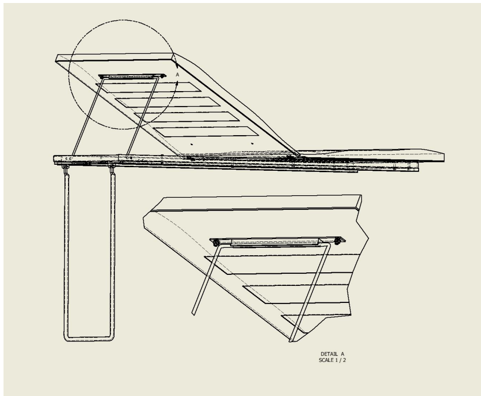
5. With all sub assemblies built, the components can be combined with bolted connections as outlined in the CAD model. Exploded views, parts lists and orthographic projections will be available as resources to aid with construction and included in the flat pack as an instructions booklet.

Figures 20 and 21 demonstrate the key operating features of this bicycle ambulance, including the the use of a reclining stretcher, a rail system to extend the stretcher behind the trailer and the removable fabric cover. The reclining functions as a result of hinges and is supported by a simple clip-in support rod. The rail system couples with a drop down support allowing it to be used as an exterior table and patients to be placed down onto the stretcher.

4.4.3 Stretcher Operation

A key feature of the stretcher design is the ability to recline to a 30 angle. This is achieved through the use of a two part flat bed connected with a hinge. Once lifted, the bed can be secured into place at the desired angle through the use of a support rod that connects to a clip on the base of the bed as shown in detail in Figure 26. The flat bed sections are manufactured from flat plate aluminium sheet. This allows for additional resistance to bending along the length of the stretcher. Additionally, the stretcher is supported by a rotating leg also demonstrated in Figure 26. This aluminium extrusion is held in place by pins and therefore locked into position by friction.

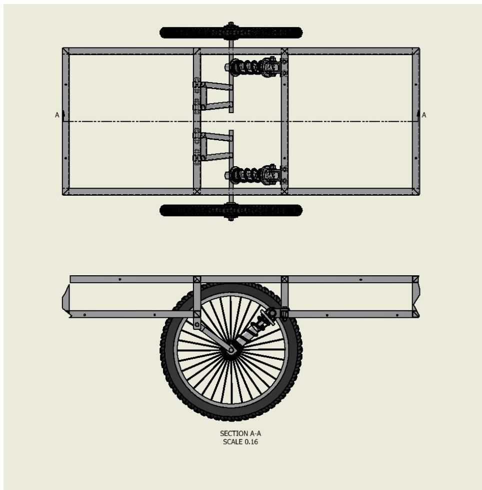
Figure 26: Stretcher Mechanism



4.4.4 Suspension Mechanism

As described in the concept development stage, the use of an angled damped spring shock absorber is optimal for this application. The section view shown in Figure 27 demonstrates how this mechanism is attached to the frame through bolted bracket connections. This is layout is sufficiently stiff to support the maximum operating loads of the bicycle ambulance. The shock absorber is located on the rear side of the wheel shaft, this allows for incoming shocks, from ground deflections, to be absorbed before they significantly impact the trailer.

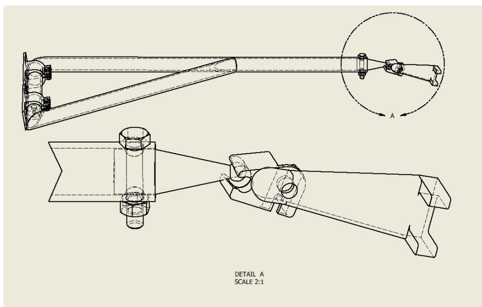
Figure 27: Suspension Mechanism



4.4.5 Hitch Mechanism

The detailed view shown in Figure 28 demonstrates the assembly of the chariot hitch employed on the trailer. The hitch tube is attached to a cast ball that fits into the cylindrical cup of the hitch. This allows the ball to be removed in only one direction, away from the wheel, whilst allowing sufficient degrees of movement to deal with pitch, yaw and roll from the trailer. The additional cast components are fitted onto the rear axle of the bicycle and ensure that the hitch itself cannot pitch under force. The components are fitted together using standard nut and bolt connections. The size of the bolt has been determined through shear force calculations which depends on the maximum tension in the hitch tube.

Figure 28: Detailed Hitch Mechanism View



5 Proving Calculations and Costs

5.1 Finite Element Analysis (FEA)

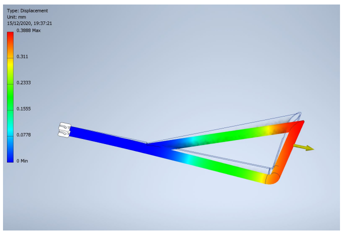


Figure 29: Trailer Hitch FEA

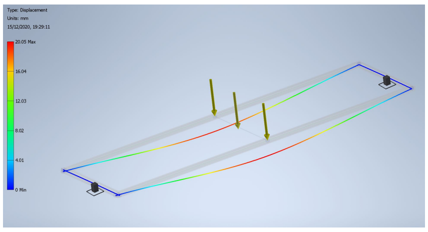


Figure 30: Stretcher Support FEA

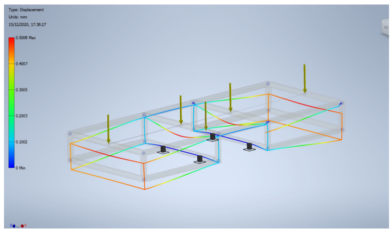


Figure 31: Frame FEA

To ensure that the materials selected through research on CES EduPack [1] would be able to withstand a worst case scenario situation, FEA has been used. For the trailer hitch connection in Figure 29, the worst case scenario load is calculated as a total of maximum rolling resistance and the impact of maximum weight at an operational incline of 20°as shown in Equation 1.

$$T_{max} = mgsec(\phi)(C_{rr}cos(\theta) + sin(\theta)) \tag{1}$$

Where T_{max} is the maximum tensile force that the hitch can experience, C_{rr} is the Coefficient of Rolling Resistance [17], m is the combined mass of trailer and patient and θ is the incline of the road and ϕ is the angle of inclination in the hitch. For this analysis, the C_{rr} has been taken as 0.01 a typical value for a mountain bike tyre while the value of θ has been taken as a maximum incline of 20. The exact value of ϕ was determined from the CAD model.

The worst case analysis for the stretcher frame is shown in Figure 30. This demonstrates the effect of the weight of a 99.99^{th} percentile male patient [18] located at the centre of the stretcher. This is an extreme scenario and does not account for the support that aluminium rails and aluminium sheet will provide. This shows that although the deflection will be in the range of $20mm$, this is not a critical deflection and will not damage the support structure. Actual values of deflection will be smaller as a result of other supporting components.

The maximum deflection value shown through FEA in Figure 31, demonstrates that the maximum percentage elongation of the frame is approximately 1.25%. This value is well below the average elongation at break for aluminium 6061. [1]

5.2 Structural Strength Requirements and Material Selection

5.2.1 Material Analysis Introduction

The purpose of this section is to analyse extreme case scenarios our design may encounter and then determine if it can withstand the resultant stresses. This analysis will define the structural requirements and use them to show whether the proposed material selection is appropriate for its respective function. All expressions of mass will be the combined mass of the trailer and a patient.

5.2.2 Axial Stress in the Bike.-Trailer Hitch

The hitch is a hollow cylindrical tube, inclined at angle ϕ. When travelling at a constant speed axial stresses generated in the hitch will be generated primarily overcoming two major forces. The first force is friction between the trailer wheels and the ground and the second is a component of the trailer weight acting parallel to the surface when travelling up a slope angle θ. The horizontal component of tension in the hitch can be expressed as a sum of these two forces

Equation (2) uses this this relationship to determine the axial stress in the hitch algebraically.

$$\sigma_{hitch} = \frac{T}{A_{hitch}} = \frac{mgsec(\phi)(C_{rr}cos(\theta) + sin(\theta))}{\pi(r_o^2 - r_i^2)} \tag{2}$$

To find σ_{max} The same values that were used to calculate F_{max} will be used. Values from r_o and r_i will be extrapolated from the CAD model.

Substituting these values into equation (2) the maximum axial stress comes out as $2.95MPa$. This is significantly lower than the minimum limit of proportionality of Aluminium 6061, $30MPa$. [19] Therefore this is an appropriate material choice for this function.

5.2.3 Shear Stress in the Bike-Hitch Trailer and Axial Stress in Suspension System

To obtain these stress values frame must be modelled as a propped cantilever system. Using this model equations can be derived for the shear stress in the hitch and the axial stress in the suspension. [3]

$$R_h = -W_p \frac{2x}{L} \tag{3}$$

$$R_s = W_t + 2W_s + W_p(1 + \frac{x}{2L}) \tag{4}$$

R_h is the shear force exerted on the hitch, T_{MSD} is the normal reaction on a single mass spring damper, W_s is the weights of the storage units, W_t is the weight of the trailer and W_p is the weight of the passenger with x being its distance from the central axis which is denoted by the dotted line. The beam has length L.

Key assumptions this model makes: The trailer can be modelled as a uniform beam, the weight of the passenger can be expressed as a single point mass which acts perpendicular to the beam and without an applied force from the weight of a passenger the trailer will balance on its wheel with no shear force exerted on the hitch.

Maximum Shear Stress on Hitch — $x = \pm\frac{L}{2}$

$$\begin{aligned} R_h &= \pm W_p \\ &= \pm 115gN \end{aligned}$$

Maximum Vertical Force on the Suspension System — $x = \frac{L}{2}$

$$\begin{aligned} R_s &= W_t + 2W_s + 2W_p \\ R_s &= 422.3gN \end{aligned}$$

For the purposes of safety calculations each storage module is modelled as containing an insulated polystyrene box entirely filled with ice. Neither of these forces are great enough will cause plastic deformation in the aluminium hitch or the mild steel compression spring, therefore these are appropriate material selections.

5.3 Modelling the Suspension

As shown in Figure 10, the suspension on the bicycle ambulance incorporates an angled shock absorber and hinge set up. The motion of such a system can be modelled through a second order differential equation:

$$m\frac{\partial^2 x}{\partial t^2} + b\frac{\partial x}{\partial t} + kx = 0 \tag{5}$$

[3] Equations (1), (2), (3) and (4) are derived, in full, in sections 8.2 and 8.3 of the Appendix

Where x is the displacement of the wheel due to a bump, m is the total weight, b is the damping constant and k is the spring constant. The damping ratio ζ of a system is the ratio of actual damping to critical damping. For this application the desirable value ζ is approximately 0.71. This is to increase comfort of the patient by not applying rapidly changing forces. In Figure 32 below, the different values of damping ratio are plotted for a constant maximum load of $195kg$ and a spring constant of $200N/m$. The purchased shock absorber must have a similar ζ value.

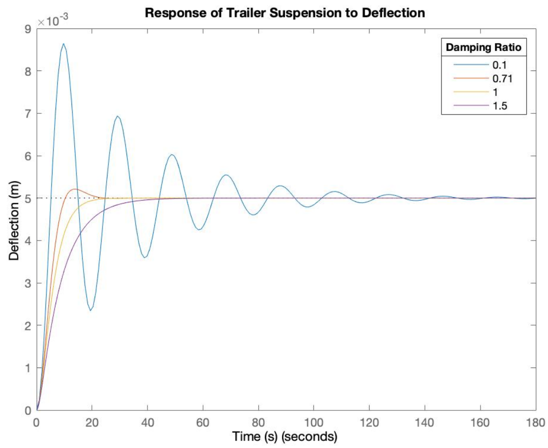


Figure 32: The Effect of Damping Ratio on Suspension Deflection

From this data, the optimal value of damping constant for the suspension is $880Ns/m$. This corresponds to a damping ratio of 0.71 and therefore will provide the greatest comfort for the patient and greatest stability to the trailer. This value of ζ corresponds to the optimal damping to resist resonance [20]. This value allows for the most rapid response to deflection, due to the spring, whilst also stiff damping to remove any oscillatory behaviour.

5.4 Preliminary Cost Breakdown

Table 2: Raw Material and Manufacturing Costs

Material/Method	Total Cost For Parts	Additional Manufacturing	Additional Cost Approximation
ABS Injection Moulding	£ 6.51		£ -
Extruded Aluminium, Purchase Cost	£ 248.47	Welding	£ 150.00
Sheet Aluminium, Purchase Cost	£ 60.00	Punching	£ 20.00
Cast Aluminium, Die Casting	£ 40.40	Surface Finish	£ 5.00
Cast Steel, Die Casting	£ 6.72	Surface Finish	£ 5.00
Polystyrene	£ 0.35		£ -
Rubber, Moulding	£ 0.03		£ -
Polyester Fabric	£ 9.07		£ -
Purchased Components	£ 87.75	Tools For Assembly	£ 2.50
Total Cost Per Unit	£ 459.28		£ 182.50
Total Combined Cost	£ 641.78		

Table 2 presents the estimated raw material and manufacturing costs for the bicycle ambulance. Assuming that the set up cost of moulds and die casts has been factored out of the product cost, the raw material column shows the approximate costs for each manufacturing method. Preliminary costs for moulds will be around £2000 depending on the size and complexity of the desired part. The cost of production of each item will decrease with volumes of production and for a quantity of over 50000, die casting over takes sand casting as the most cost efficient casting method [21].

The assumed welding cost incorporates an average salary [22], material and energy costs involved in the process. Other additional costs are estimated using the time required for completing the process and the same average salary. These are extremely conservative estimates and the NGO must partner with manufacturing companies to detail the exact costs of production. Through this cost breakdown, the initial indicative cost of production per unit is estimated at £641.78. This fulfills the cost requirements outlined in the specification and therefore allows this product to be financially viable.

6 Numerical Analysis of Heat Transfer

6.1 Background

From the design brief [6]:

"A number of high-level requirements have already been identified by the customer... "Consideration of the specific storage needs of critical medication e.g. vaccines"

Subsequently the ambulance will be designed with an adequate storage facility for vaccinations. The vaccine unit will be an insulated container module, able to be carried in one or more of the four storage spaces in the frame. The thermal behaviour of the container will be modelled mathematically using MATLAB and further calculations will be carried out to determine whether it is successful in completing the desired insulating function.

6.2 Modelling Technique

The modelling methodology is as follows. The system will be divided into a large network of cubes. Each cube is capable of transmitting and receiving heat out of one of its six faces. These sub-divisions are called nodes. Applying this, there are four types of nodes in this model: an internal node, a face node, an edge node and finally, a corner node. These nodes are considered different as the ratio of sides that experience conduction to the sides that experience convection vary for each. Different categories has different equations determining and modelling their thermal behaviour. These equations will be derived in terms of material conductivity (k), convective heat transfer coefficient (h), node dimension (d), the ambient temperature (T_{amb}) and adjacent node temperatures. All assumptions made will be highlighted. The first key assumption is thermal energy can only pass in an orthogonal direction from a nodes face.

$$Q_x = kA\frac{\delta T}{\delta x} \quad (6) \qquad\qquad Q = hA\Delta T \quad (7)$$

The second key assumption is as follows: There is no energy stored within a node. Translating this into a formula the general result for any node in the model is:

$$\sum (Q_{(i)} \rightarrow Q_{(x,y,z)}) = 0 \quad (8)$$

6.2.1 Internal Nodes

All faces on internal nodes will conduct heat as they are surrounded by other elements. Using equations (6) and (8) the following result can be derived:

$$T_{(x,y,z)} = \frac{T_{(x+1,y,z)} + T_{(x-1,y,z)} + T_{(x,y+1,z)} + T_{(x,y-1,z)} + T_{(x,y,z+1)} + T_{(x,y,z-1)}}{6} \quad (9)$$

This type of node will be modelled using a 3D convolution function (convn)

6.2.2 Face Nodes

Face nodes have five shared faces and one external face. Which adjacent node temperatures you take depends on what plane the relevant node sits in. In this equation the node in question sits in the x-y plane. Using equations (6), (7) and (8) the following result can be derived:

$$T_{(x,y,z)} = \frac{k}{5k+hd}(T_{(x+1,y,z)} + T_{(x-1,y,z)} + T_{(x,y+1,z)} + T_{(x,y-1,z)} + T_{(x,y,z+1)}) + \frac{hd}{5k+hd}T_{amb} \quad (10)$$

6.2.3 Edge Nodes

Edge nodes have four shared faces and two external faces. Which adjacent node temperatures depends which axis the edge runs in parallel with. In equation the node in consideration will sit on the x axis. Again using equations (6), (7) and (8) the following result can be derived:

$$T_{(x,y,z)} = \frac{k}{4k+2hd}(T_{(x+1,y,z)} + T_{(x-1,y,z)} + T_{(x,y+1,z)} + T_{(x,y,z+1)}) + \frac{hd}{2k+hd}T_{amb} \quad (11)$$

6.2.4 Corner Nodes

Corner nodes have three shared faces and three external faces. Which adjacent node temperatures are considered depends on which of the eight corners you select. The node being considered in this equation is the corner closest to the origin. Finally using equations (6), (7) and (8) the following result can be derived:

$$T_{(x,y,z)} = \frac{k}{3(k+hd)}(T_{(x+1,y,z)} + T_{(x,y+1,z)} + T_{(x,y,z+1)}) + \frac{hd}{k+hd}T_{amb} \tag{12}$$

6.3 Modelling the System Using MATLAB

6.3.1 Defining Constants

The first stage defines the constants mentioned in section 6.2. The system dimensions must also be defined. These dimensions must include the external and internal boundary dimensions. In this model the external and internal boundaries represent the outer and inner walls of the storage unit respectively.

Boundary dimensions are extrapolated from the measurements of the storage container. The ambient temperature taken as 51.3°C, the hottest ever recorded temperature in Africa. [13] Internal temperature will be set at 0°C. Conductivity will be that of polystyrene, 0.033. The convective heat transfer coefficient set at $5W/m^2K$, the convection coefficient of free convection with a significant temperature gradient. [23]. The element size is set at 0.002 metres.

6.3.2 Setting Up An Iterative Loop For heat Transfer Equations

By creating a loop that runs while the percentage difference between two successive iterations is is greater than 0.01%, substituting equations (9) through (12) into this loop and finally repeating and adapting the equations so every node undergoes the correct thermal transformation, this model will tend towards thermal equilibrium. From there the heat output of the container can be calculated allowing the suitability of the container to be determined.

6.3.3 Thermal Equilibrium Results

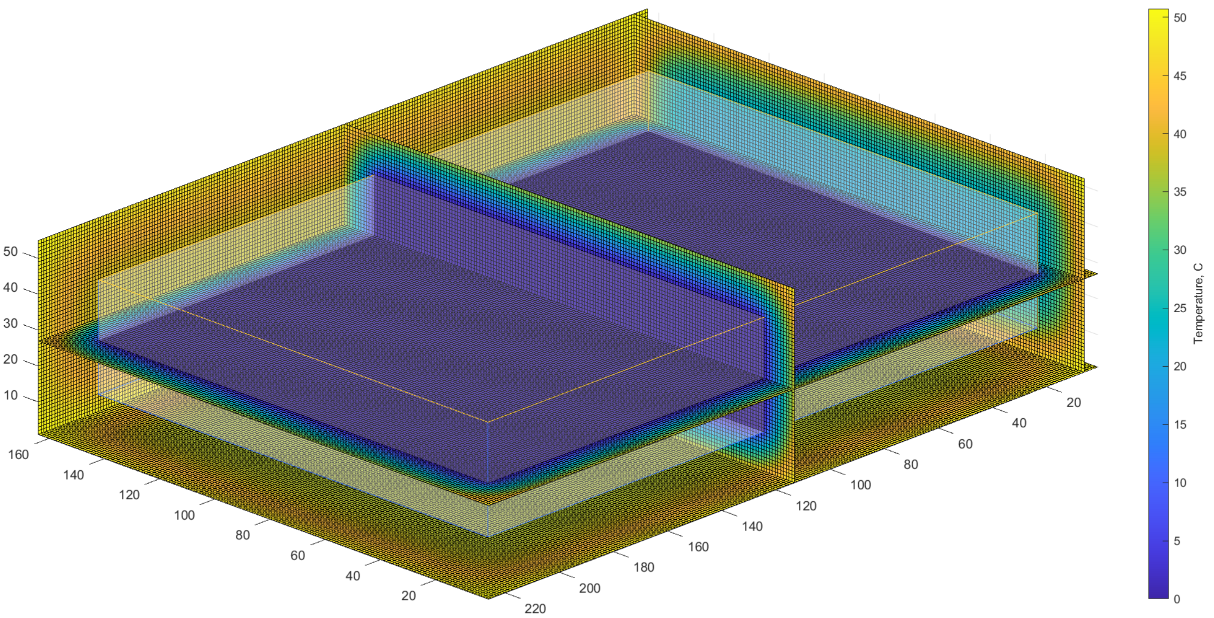


Figure 33: Heat Distribution of Storage Container When At Equilibrium

The transparent box in the centre represents the internal boundary dimensions.

6.3.4 Calculating Rate of Heat Transfer From the Sink

Now a model has been obtained for the thermal equilibrium of the storage unit analysis can be carried out. The rate of heat dissipating via conduction from the sink needs to be calculated in order to determine how long it would take for a set amount of ice within the container to melt. The rate of heat being dissipated from each node on the sink's surface can be calculated using an extended version equation (6). Since, in this application of the equation, $A = (Element\ Size)^2$ and $\partial x = Element\ Size$ equation (6) collapses down to:

$$Q_x = k \times (Element\ Size) \times \delta T \tag{13}$$

This equation will provide the rate of dissipation from each node on the surface of the sink. By storing each of these values in a matrix and finally summing them the total rate of dissipation of the sink can be calculated.

6.3.5 Calculating Time Taken for Ice to Melt in Storage

The energy required to melt any material can be calculate using the equation:

$$Q_f = mL_f \tag{14}$$

Where L_f is the latent heat of fusion. The substance in the storage box will be ice. For ice $L_f = 3.34 \times 10^5 J/kg$ and $\rho = 916.8 kg/m^3$. [24]

Finally to work out the time it would take for the ice to melt divide the energy required to melt the ice by the rate of energy transfer and convert the resultant time to hours:

$$t = \frac{Q_f}{Q_x \times 3600} \tag{15}$$

6.4 System Optimisations

The sink temperature is reset after every iteration, therefore the maximum temperature gradient and subsequently the maximum energy dissipation is maintained throughout. As a result this model produces a conservative estimate of the melting time. The real value will in fact be higher. In the original model the wall thickness was set to 30mm. This calculated that when container was a third filled with ice it would take at least 41 hours to melt. This is unnecessarily high. The minimum melting time will be 24 hours. Using the model in reverse it can be calculated that the thickness can be decreased to 20mm. This increases volume of storage by 14.2% and reduced the melting time to 25.5 hours. Figure 34 shows the final system model.

By adding circular fillets to each vertical edge the surface area and therefore the rate of heat dissipation in the corners can be decreased by a factor of $\frac{4}{\pi}$ (21.4%). Despite decreasing storage volume, the benefits of this change out weigh the drawback.

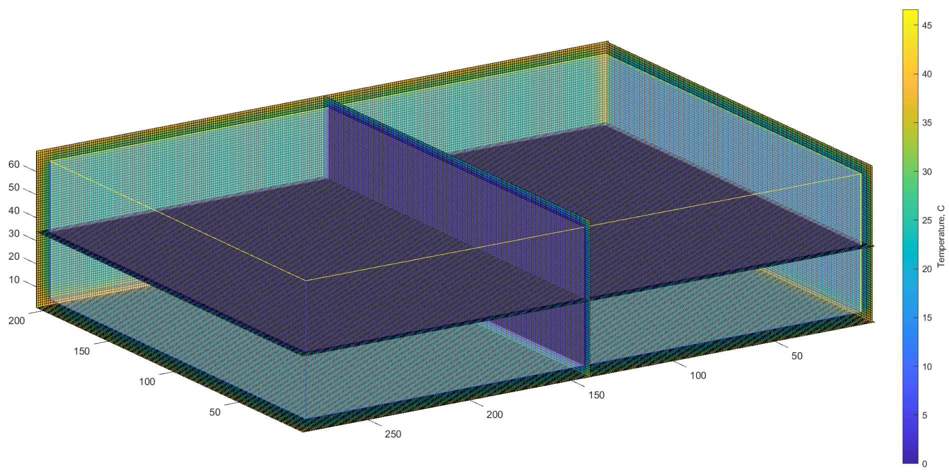


Figure 34: Heat Distribution of Storage Container When At Equilibrium with Amended Wall Thickness

7 Evaluation

Evaluation of the final product shows that the design process has been a success. Analysing the product with respect to the specification generated in section 1.2, reveals that all demand criteria have either been satisfied or addressed. The final design satisfied the safety, storage, durability and manufacturing requirements in their entirety. User comfort was accounted for through effective material selection and extrapolation of anthropometric data, cost requirements were met with the unit coming in under-budget and any maintenance required can be carried out quickly and easily with minimal training. The problem statement that was derived in section 1.1 has been satisfied in its entirety. Effective sub-system design and further material selection ensured the product satisfied all required functional requirements and aided in delivering a fully functional and marketable product. However, as with all design, there were some oversights and areas to be improved.

Throughout the design process, there has been little consideration for the sustainability of the product, going against the specification points 9.01 and 9.02. Further developments would include considering the manufacturing and supply chains in more detail, ensuring that all necessary measures to promote sustainability are taken. Examples of such practices could include minimal reliance on single-use plastics and the increasing use of recycled materials, for example the polyester used for the cover.

By focussing on use of a reclined stretcher, this design is advantageous for a majority of medical emergencies such as pregnancies and small scale fracture injuries. It improves blood circulation and patient comfort during transportation. However, for patients with extensive spinal injuries it is important that the affected area is immobilised. This could be achieved through use of a neck brace and back support built into a stretcher. The final design does not include these features and therefore is not optimised for such injuries. As this is a far less common use for the ambulance these drawbacks are not critical but add to future developments on this product.

The numerical analysis, whilst providing valuable insight into the insulated storage units' effectiveness, is a flawed model. Time taken for the MATLAB script to run increased exponentially as element size decreases. For this reason, the element size had to be kept relatively high therefore reducing the models resolution. At the considered range, the rate of dissipation changed significantly with element size. This brings the accuracy of this model into doubt. Given more time the node size would have been significantly reduced and the code allowed to run for longer, as to produce a high-resolution model and an accurate rate of heat transfer.

The frame is manufactured using TIG welding. In the context of Sub-Saharan Africa this is an advanced process that is not readily available. This limits the potential production location significantly to countries with more developed manufacturing capabilities such as South Africa and Kenya. Further iterations of the design could potentially investigate simplifying the frame structure by relying on bolted rather than welded connections. Whilst reducing the frame strength this could increase the number of potential manufacturing locations, reducing shipping costs as well as the production costs. Mass is an objective function. This means it is a value to be optimised, in this case minimised. Additional improvements can be made to the total mass of the ambulance. This would increase the ease of use and allow larger distances to be covered. By removing some frame elements, determined through frame analysis and topology optimisation software, the mass can be reduced with minimal impacts on the strength of the structure.

The final significant drawback of the design is that the paramedic cannot see the patient when the cover is up. This is required in case of a medical emergency. Further adaptations of the design could look into fitting a rear view mirror and making sections of the cover transparent to ensure a clear line of sight.

To conclude, this report shows the transition from a design brief to a marketable product. The final design accounts for all demanded specification points, standing as a feasible and marketable product. Whilst significant flaws still exist in this version of the design, through further iterations these can be reduced to a point where the solution to the problem statement is faultless.

8 Appendix

8.1 MCDA Down-Selection for Final Concepts

Table 3: MCDA Analysis of Phase A Final Concepts

Category	Weighting	Group 1 Score	Weighted Score	Group 2 Score	Weighted Score
Safety	5	5	25	5	25
Storage	5	5	25	3	15
Comfort	1	4	4	4	4
Function	5	5	25	5	25
Manufacturing	3	4	12	4	12
Durability	4	4	16	4	16
Maintenance	3	4	12	5	15
Economic Factors	2	4	8	5	10
Sustainability	2	3	6	3	6
Accessibility	5	5	25	5	25
Total	-	-	**158**	-	**153**

8.2 Axial Hitch Stress Derivation

Balancing Forces Parallel to the Slope:

$$\begin{aligned}
Tcos(\phi) &= F + mgsin(\theta) \\
&= C_{rr}R + mgsin(\theta) \\
&= C_{rr}mgcos(\theta) + mgsin(\theta) \\
&= mg(C_{rr}cos(\theta) + sin(\theta)) \\
T &= mgsec(\phi)(C_{rr}cos(\theta) + sin(\theta)) \\
\sigma_{hitch} &= \frac{T}{A_{hitch}} \\
&= \frac{mgsec(\phi)(C_{rr}cos(\theta) + sin(\theta))}{\pi(r_o^2 - r_i^2)}
\end{aligned}$$

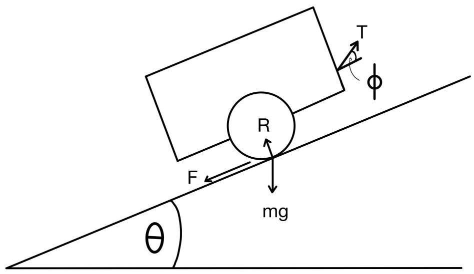


Figure 35: Force Diagram of Trailer on a Hill

8.3 Shear Hitch Stress and Suspension Compression Force Derivation

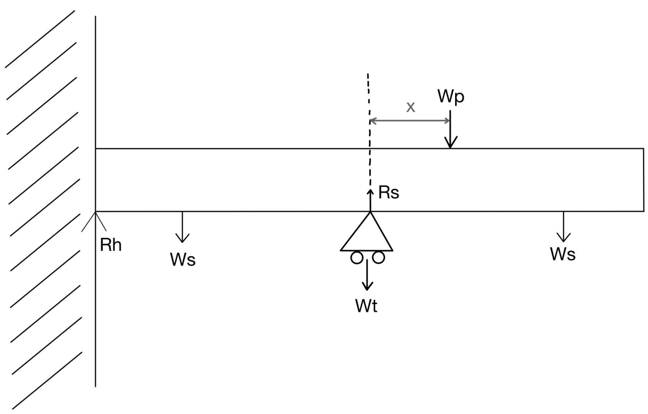


Figure 36: Frame Represented as a Propped Cantilever

Taking Moments Around the Centeral Axis:

$$-\frac{R_h L}{2} = W_p x$$
$$R_h = -\frac{W_p x}{2L}$$

Balancing Vertical Forces:

$$R_s + R_h = W_p + W_t + 2W_s$$
$$R_s = W_p + W_t + 2W_s - R_h$$
$$R_s = W_p + W_t + 2W_s + \frac{W_p x}{2L}$$
$$R_s = W_t + 2W_s + W_p(1 + \frac{x}{2L})$$

8.4 Bill Of Materials

Table 4: Bill of Materials (1)

Part Number	Mass Per Unit	Material	Mass of Parts	Estimated Cost
StorageDrawer	2.012	ABS Plastic	8.048	£ 4.43
CoverSupport2	0.701	ABS Plastic	0.701	£ 0.39
CoverSupport1	0.522	ABS Plastic	0.522	£ 0.29
StorageFlap	0.494	ABS Plastic	1.976	£ 1.09
StorageHinge	0.113	ABS Plastic	0.452	£ 0.25
StretcherReclinerConnection	0.077	ABS Plastic	0.077	£ 0.04
Storage Lock	0.015	ABS Plastic	0.060	£ 0.03
StretcherSupport	2.242	Aluminum 6061	4.484	£ 60.00
WheelRim	1.814	Aluminum 6061	3.628	
BS 4848 - 30 x 30 x 3 HFRHS - 2070	1.657	Aluminum 6061	3.314	
StretcherRailFe	1.508	Aluminum 6061	3.016	£ 0.70
CoverSupportLength	1.079	Aluminum 6061	2.158	£ 0.40
BS EN 10219-2 - 40 x 40 x 3 - 820	0.894	Aluminum 6061	0.894	
BS EN 10219-2 - 40 x 40 x 3 - 836.48528137	0.888	Aluminum 6061	0.888	
BS EN 10219-2 - 40 x 40 x 3 - 836.485	0.888	Aluminum 6061	4.443	
BS EN 10219-2 - 40 x 40 x 3 - 800	0.878	Aluminum 6061	0.878	
HitchTube	0.875	Aluminum 6061	0.875	£ 2.50
SusBase	0.845	Aluminum 6061	1.690	
BS EN 10219-2 - 40 x 40 x 3 - 779.328	0.831	Aluminum 6061	0.831	
BS EN 10219-2 - 40 x 40 x 3 - 786.485	0.831	Aluminum 6061	5.821	
StretcherRailMa	0.738	Aluminum 6061	1.476	£ 1.00
SusCaps	0.665	Aluminum 6061	1.330	
WheelShaft	0.617	Aluminum 6061	1.234	£ 1.00
BS EN 10219-2 - 40 x 40 x 3 - 538.243	0.558	Aluminum 6061	0.558	
BS EN 10219-2 - 40 x 40 x 3 - 536.485	0.547	Aluminum 6061	0.547	
StorageRails	0.523	Aluminum 6061	2.092	£ 2.00
WheelHub	0.470	Aluminum 6061	0.940	
SusHingeBase	0.394	Aluminum 6061	0.788	£ 16.00
BS 4848 - 30 x 30 x 3 HFRHS - 447	0.339	Aluminum 6061	0.678	
StretcherRailSupport	0.335	Aluminum 6061	0.335	£ 5.50
BS EN 10219-2 - 40 x 40 x 3 - 236.485	0.206	Aluminum 6061	0.619	
BS EN 10219-2 - 40 x 40 x 3 - 236.48528137	0.206	Aluminum 6061	0.206	
BS EN 10219-2 - 40 x 40 x 3 - 218.243	0.201	Aluminum 6061	0.805	
StretcherSupportRod	0.176	Aluminum 6061	0.176	£ 4.50
BS EN 10219-2 - 30 x 30 x 3 - 200	0.162	Aluminum 6061	0.324	
BS EN 10219-2 - 30 x 30 x 3 - 200.655	0.158	Aluminum 6061	0.316	
BS EN 10219-2 - 30 x 30 x 3 - 130	0.093	Aluminum 6061	0.186	
BS EN 10219-2 - 30 x 30 x 3 - 65.438	0.049	Aluminum 6061	0.098	
BS EN 10219-2 - 30 x 30 x 3 - 79.125	0.048	Aluminum 6061	0.096	
CoverFrameAttachment	0.022	Aluminum 6061	0.088	£ 6.00
StretcherHinge1	0.003	Aluminum 6061	0.006	£ 6.00
StretcherHinge2	0.003	Aluminum 6061	0.006	£ 6.00
LegPin	0.002	Aluminum 6061	0.004	£ 0.50
StretcherLeg	0.854	Aluminum 6061, Welded	0.854	£ 0.75
CoverFabric1	0.259	Polyester	0.259	£ 0.91
CoverFabric2	1.001	Polyester	2.002	£ 7.01
CoverFabric3	0.329	Polyester	0.329	£ 1.15
CoolerBox	1.266	Polystyrene	1.266	£ 0.08
Cushion2	2.012	Polystyrene	4.024	£ 0.24

Table 5: Bill of Materials (2)

Part Number	Mass Per Unit	Material	Mass of Parts	Estimated Cost
Cooler Box Lid	0.468	Polystyrene	0.468	£ 0.03
WheelTyre	1.897	Rubber	3.794	
RailStopper	0.008	Rubber	0.016	£ 0.03
WheelSpoke	0.044	Steel, Alloy	1.408	
HitchFrameLock	0.132	Steel, Cast	0.132	£ 0.36
HingeBall	0.104	Steel, Cast	0.104	£ 0.28
HitchCup	0.062	Steel, Cast	0.062	£ 0.17
WheelSpoke_MIR	0.045	Steel, Cast	1.440	
HitchTrailerAttachment	0.045	Steel, Cast	0.090	£ 0.24
Compress Spring1	1.359	Steel, Mild	2.718	
SusAttachment	1.045	Steel, Mild	2.090	£ 5.66
ANSI B18.2.3.5M - M20 x 2.5 x 100	0.328	Steel, Mild	0.656	£ 1.78
ANSI B18.2.3.5M - M14 x 2 x 80	0.124	Steel, Mild	0.496	£ 1.34
ANSI B18.2.3.5M - M14 x 2 x 75	0.118	Steel, Mild	0.472	£ 1.28
ANSI B 18.2.4.1 M - M20 x 2.5	0.076	Steel, Mild	0.152	£ 0.41
ANSI B18.2.4.6M - M14 x 2	0.043	Steel, Mild	0.258	£ 0.70
ANSI B18.22M - 24 N	0.036	Steel, Mild	0.144	£ 0.39
ANSI B18.2.3.5M - M8 x 1.25 x 70	0.034	Steel, Mild	0.272	£ 0.74
ANSI B18.3.1M - M8x1.25 x 65, FSHCSM	0.033	Steel, Mild	0.132	£ 0.36
ANSI B18.2.4.2M - M14 x 2	0.030	Steel, Mild	0.120	£ 0.33
ANSI B18.2.3.5M - M8 x 1.25 x 45	0.024	Steel, Mild	0.024	£ 0.07
IFI 513 - M8x1.25 x 55, CRFCHMSTIM(1)	0.024	Steel, Mild	0.192	£ 0.52
IFI 513 - M8x1.25 x 40, CRFCHMSTIM	0.018	Steel, Mild	0.072	£ 0.20
ANSI B18.22M - 16 N	0.016	Steel, Mild	0.256	£ 0.69
ANSI B18.2.3.5M - M6 x 1 x 35	0.011	Steel, Mild	0.044	£ 0.12
IFI 513 - M8x1.25 x 16, CRFCHMSTIM	0.008	Steel, Mild	0.016	£ 0.04
ANSI B18.2.3.5M - M6 x 1 x 20	0.007	Steel, Mild	0.021	£ 0.06
ANSI B 18.2.4.1 M - M8 x 1.25	0.006	Steel, Mild	0.168	£ 0.46
ANSI B18.22M - 8 N	0.004	Steel, Mild	0.016	£ 0.04
ANSI B18.6.7M - M5x0.8 x 16, CRPHMSTIM(1)	0.004	Steel, Mild	0.016	£ 0.04
ANSI B18.2.4.2M - M6 x 1	0.003	Steel, Mild	0.006	£ 0.02
ANSI B 18.2.4.1 M - M6 x 1	0.003	Steel, Mild	0.012	£ 0.03
IFI 513 - M6x1 x 10, CRFCHMSTIM	0.003	Steel, Mild	0.024	£ 0.07
ANSI B 18.2.4.1 M - M5 x 0.8	0.002	Steel, Mild	0.008	£ 0.02
ANSI B18.2.4.5M - M6 x 1	0.002	Steel, Mild	0.016	£ 0.04
ANSI B18.22M - 5 N	0.001	Steel, Mild	0.004	£ 0.01
Sum of 30x30x3				£ 56.64
Sum of 40x40x3				£ 173.88
Wheel Complete				£ 58.00
Suspension Complete				£ 20.00
Total for Raw Material			82.316kg	£453.78

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