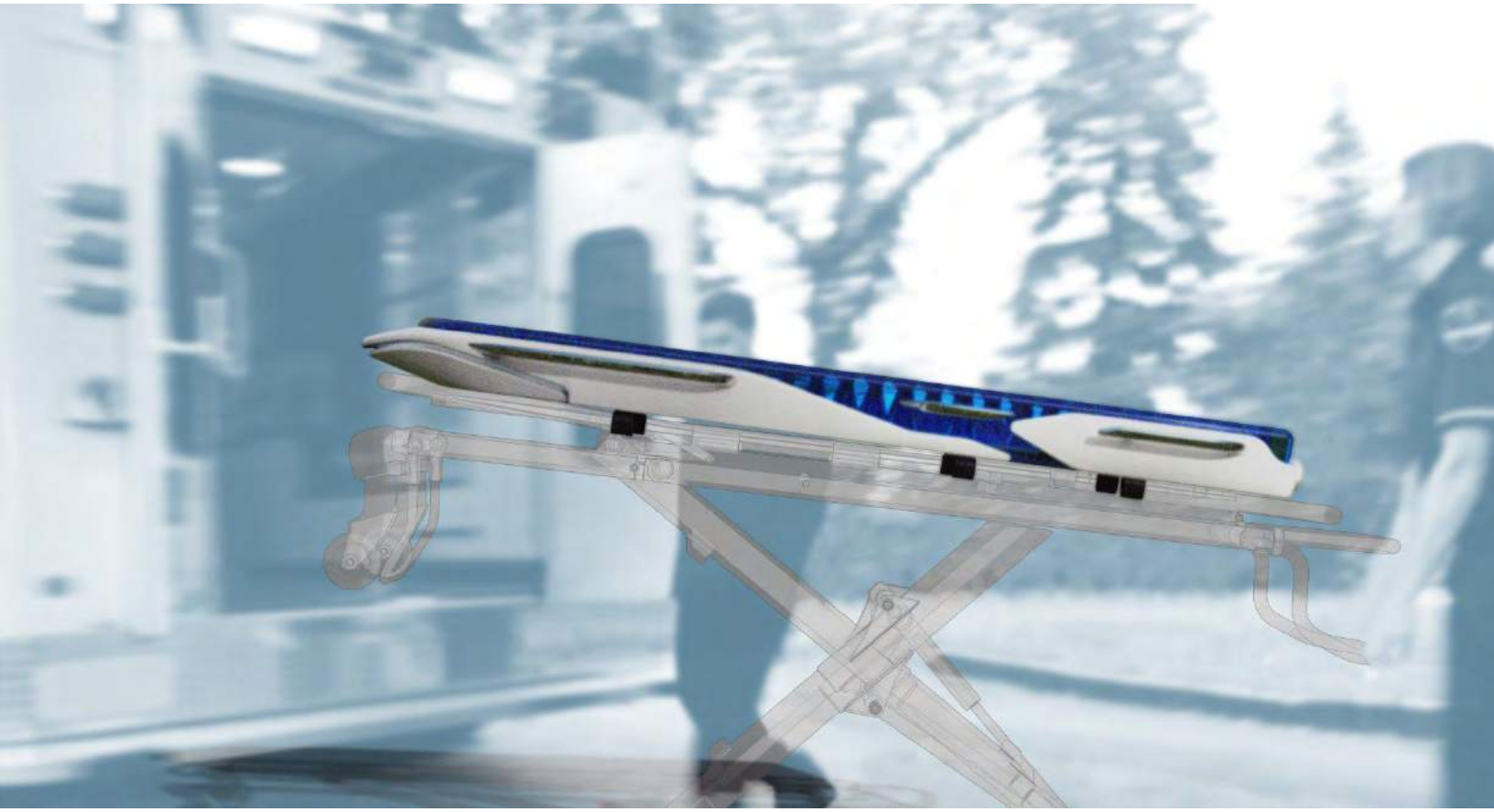
ZEROCODE

A smart stretcher mattress system



RAYMOND DANIEL

Industrial Design Thesis Report

How may we improve the efficiency of patient transfer?

by

Raymond Daniel

Submitted in partial fulfillment of the requirements for the degree of

Bachelor of Industrial Design

Faculty of Applied Sciences &Technology
Humber Institute of Technology and Advanced Learning

Supervisors: Catherine Chong and Sandro Zaccolo

April 18, 2022

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Abstract

A silent crisis is developing in the medical industry; offload delay is on the rise. Offload delay begins 30 mins after a paramedic team arrives at a receiving hospital and signifies the time elapsed before paramedic's hands over patient care to the hospital. One of the leading causes of offload delay is overcrowded emergency departments. At the same time, the demand for emergent patient transfer is increasing. The delay keeps paramedics in hospitals, reducing the number of available paramedics responding to a city's emergencies. Occasionally, all paramedics within a city will become unavailable, resulting in a city's inability to respond to new emergencies; this is sometimes referred to as a CODE 0. Additionally, during busy times in the emergency department, effective communication between paramedics and receiving medical professionals can begin to break down, possibly leading to delays later. Finally, cleaning and filing medical charts can further delay the paramedic team from becoming available for the next patient. The ZEROCODE system addresses this problem on multiple fronts. The ZEROCODE system increases the efficiency in multiple components of patient transfer, from the reduction of the number of wires connected to the patient to storing and transferring patient data in real-time. This thesis project will use various research methods to understand the needs of both critical care paramedics and their patients. Information will be gained through sources such as interviews and user observational studies. Sources for primary research will originate from existing contacts in the first-responder industry with the intent to meet new sources through secondary connections. Additionally, preliminary research will be directed and fortified by secondary research methods such as literary reviews. The information gathered from this investigation has the potential to help not only paramedics but also all who use their services. Driven by the data collected, an evidence-based solution will be tested through sketch models and a full-size mock-up to evaluate the design's ergonomics. The final solution will potentially allow critical care paramedics to save lives more effectively.

Keywords: paramedic, efficiency, offload delay, patient transfer

Acknowledgements

The success of this project is due in large part to the support network around me. This includes my direct supervisors, industry advisor, program professors and fellow classmates. Their generous support helped me gain knowledge of the often-thankless efforts of paramedics, guided my creativity, and provided feedback. In no particular order, I would like to thank the following people.

I would like to thank Catherine Chong and Sandro Zaccolo who were my primary supervisors during this thesis project. Their sharp sense of design and experience helped to elevate this project to the next level. Their contributions helped to focus the design and refine the styling.

Additionally, I must thank my advisor as well as all of those who helped provide insight into the world of critical care paramedics and nurses. Their time and willingness to share their insight helped develop a strong base of facts and knowledge to allow the entirety of the project to stand. Furthermore, I would like to acknowledge and thank my classmates for their enduring friendship, support and feedback throughout this project and program.

Finally, I would like to thank my girlfriend and family. The love, encouragement, and support from my girlfriend Vanessa kept me strong and focused through late nights and times of doubt. My family and their continuous love and support allowed me to focus on my studies and this project.

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CHAPTER 1 Introduction

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1.1 Problem Definition

Paramedics are the symbol of hope and reassurance to those who are ill or injured (Toronto Paramedic Service, 2018). In 2019, the Toronto Paramedic Service responded to 316 324 calls and performed 226 390 transfers. Paramedics specialize in pre-hospital care and the transportation of patients from an emergency scene to a hospital or from one hospital to another all while providing a suitable level of care to the patient. However, there are several inefficiencies with the flow of patient information in multiple different avenues. First, there is an increased need for more land ambulances in Ontario combined with an increase in offload delay (Pasma, 2020). Offload delay is additional time spent by a paramedic with a patient at a hospital beyond the regular amount(Pasma, 2020). Secondly, when Emergency Medical Services (EMS) arrives at the hospital with a patient, a clinical handover with a verbal briefing occurs between the paramedics and the receiving trauma medical staff (Javidan et al., 2020). Again, this verbal only approach could lead to miscommunication, the omission of crucial information due to human error on the paramedics' part or the loss of information due to the receiving medical staff forgetting or not listening to the details of the patient(Javidan et al., 2020).

1.2 Rationale and Significance

No one knows when they will need the help of a paramedic and trauma team. However, it is in everyone's interest to increase the effectiveness of pre-hospital medicine. To define the scope of the project it is important to understand the current landscape of pre-hospital care which include learning about the following:

1. Who are the **stakeholders** associated with the transportation of ill or injured patients?
2. Where are the **environments of operation**?
3. What are the **demographics** of the primary stakeholders?
4. What **equipment** is necessary for paramedics to perform their duties effectively?
5. What **products** are currently on the market?
    a. What are their **benefits and features**?
    b. What are some of their **drawbacks**?
6. What are the basics of their professions? What does the **terminology** mean?

Once a basic paradigm is established, educated questions can be asked to further empathize with paramedics and their patient. The following questions require answers:

1. What is the **lived-in experience** of a paramedic and critical care paramedic?
2. What are the **needs and wants** of a **paramedic** during a shift?
3. What are the **needs and wants** of a **patient** during transportation?
4. What **ergonomic challenges** exist for both the patient and paramedic?

A variety of methods will be employed to learn the answers to the questions posed above. These methods of gathering insight include:

- Literature Review
- Video observation
- 1:1 Semi Structured interviews
- User Observation
- Ergonomic Studies
- Semantics Analysis

Through various methods of gaining insight into the world of a paramedic, a project scope, and paradigm will be created. The answers to the above questions will form a strong base in which a design is built.

1.3 Background, History and Social Context

The paramedic profession is a diverse group of individuals. However, on average paramedics are taller than the general population and both the men and women are heavier than U.S. military personnel (Guan et al., 2020). According to Glassdoor, the average salary of a critical care paramedic in Canada is 129 723 dollars(Glassdoor, 2021b). As of 2019, 35.2 percent of paramedics in Ontario were female (Canadian Institute for Health Information, 2020). Of all paramedics in Ontario, 72.7 percent are between the ages of 30 and 59 (Canadian Institute for Health Information, 2020).

Paramedics are on duty usually 12 hours per shift (ItsBandage, 2020). Due to the need for coverage 24 hours a day, paramedics usually work shift work sometimes requiring them to work the night shifts. This fluctuating schedule can sometime make it difficult to plan (ItsBandage, 2020). There are also minimal breaks, and stressful situations (ItsBandage, 2020).

Paramedicine in the media is often portrayed as a high intensity, adrenaline-soaked race against time. While there is some truth to this, the majority of the time is spent preparing the ambulance, patient charting, waiting for calls or treating non-life-threatening calls (ItsBandage, 2020).

CHAPTER 2 Research

A new product potential can be carefully triangulated by gathering data on potential stakeholders, their environments and the current products that are being used. Information was collected through several methods including user observation, interviews with stakeholders, literature reviews and benchmarking of current products.

2.1 User Research

An investigation into the target user within the pre-hospital medicine field allows for a deeper understanding of their lived-in experience while on duty. This is achieved through a collection of data of their activities and use of current products. Additionally, there will be a focus on the health and safety of the current products as well as the human factors.

2.1.1 User Profile - Persona

Paramedics do not work in solitude but rather are part of a large health care network dedicated to the care and preservation of the health of patients. To better understand the potential users of a new product this report categories the potential primary, secondary and tertiary users.

Method

Literature reviews and video observations were used to acquire an understanding of those who are involved in the pre-hospital medicine and patient transfers. Furthermore, information was gathered from, and reviewed with the project advisor.

Results

While both the patient and paramedic could be considered primary users, the paramedic must clean, maneuver, interact, and store medical devices. Therefore, the paramedic is considered the primary user.

Primary User: Paramedic (Primary Care, Advanced Care and Critical Care)

Secondary User: Patient (1st percentile to 99th percentile, of both genders)

Tertiary User: Nurse (Intensive Care Unit, Triage, Emergency Department, etc.)

Demographics

Paramedics are a diverse group of people who range in gender, age, body type and race. However, in Ontario the profession is still made up of a majority of males with a roughly 65% - 35% split male to female (Canadian Institute for Health Information, 2020). Additionally, the majority of paramedics are of the ages 30 to 59 (Canadian Institute for Health Information, 2020). A study of paramedics in the United States determined that 3 percent of the paramedic population was Black and 10 percent were Hispanic with a large majority of the paramedics being reported as White (Crowe et al., 2020). Paramedics are paid an average of 73 000 dollars a year in Canada (Glassdoor, 2021a) while critical care paramedics are compensated for their advanced medical knowledge and are paid an average 129 723 dollars per year (Glassdoor, 2021b). See figure 2 for this project's persona.

Figure 2 - Persona: Advanced Care Paramedic

The User Behaviour

Bernard finished high school and knew he wanted to help people for a living. Looking at all the options within the field of health care, Bernard chose to pursue paramedicine. He completed his two-year diploma in paramedicine at Humber College before working in the field as a primary care paramedic (PCP) for two years. He than further developed his skills through a one-year Advanced Care Paramedic (ACP) program with ORNGE Ambulance Service[1]. Bernard has worked as an Advanced Care Paramedic for the last 3 years.

He sometimes finds it difficult because it is hard to create plans with other people in advance due to the nature of shift work (ItsBandage, 2020). He can never be sure when he will have a night shift or a weekend free. However, when he doesn't make plans, he enjoys hiking and rock climbing with his friends. He is also an amateur wood worker and builds projects in his small workshop behind his house.

[1] Correspondence with project Advisor, September 27, 2021 – See Appendix B

2.1.2 Current User Practice

While on duty, but not on calls, Bernard is responsible for ensuring that the medical equipment is properly stocked in his ambulance and ensures that all of the drugs are not out of date (Really, 2021). The number of calls that come in per day is highly variable, however, the pace of the day is generally fast and there is not a lot of downtime (ItsBandage, 2020).

Method

Interview responses from both the project's advisor as well as other interviewees were fortified with day-in-the-life videos of paramedics on streaming platforms like YouTube.

Regular Tasks, Procedures and Attitudes

A primary care and advanced care ambulance team generally perform patient transport from the scene of an accident to a nearby trauma center. A critical care paramedic (CCP) team can perform both patient transport from the scene of an accident as well as the interfacility transfers (a transfer of a patient from one hospital to another which specializes in a specific procedure)[1]. All paramedics are held to a strict scope of practice and are granted permission to perform specific controlled acts from a physician. The level of accreditation a paramedic possesses determines the level of care they can provide. For instance, a primary care paramedic can perform Cardiopulmonary Resuscitation (CPR), monitor oxygen saturation (SpO_2) and interpret a 12 Lead Electrocardiogram (ECG). A CCP on the other hand, can interpret chest X-Rays, administer blood products, and transfer patients on mechanical ventilation (Toronto Paramedic Association, 2021).

When an ambulance arrives at the hospital paramedics must transfer the care of the patient to the receiving hospital medical staff before leaving (Pasma, 2020). This transfer of care requires the

[1] Correspondence with project Advisor, September 27, 2021 – See Appendix B

paramedics to brief the receiving medical staff about a variety of topics related to the incoming patient (Javidan et al., 2020). The completeness and effectiveness of this briefing is highly variable depending on distractions, quality of reporting from the paramedics and the quality of listening done by the receiving medical staff(Javidan et al., 2020). Javidan et al. (2020) found that 61% of patient handovers contained concurrent conversations during the paramedic's brief and that 35% of all questions asked by the receiving nursing and trauma team revolved around previously discussed material. Furthermore, Javidan et al. (2020) reported instances of paramedics leaving out potentially useful patient information. In general, the following nine topics should be addressed during a patient hand over (Javidan et al., 2020):

1. Identification
2. Mechanism of Injury
3. Injuries Identified
4. Signs and Symptoms
5. Treatment and Trends
6. Allergies
7. Medications
8. Background History
9. Other Information

Of 79 patient care transfers, only 68% of the handovers included information regarding enroute treatment, 0% of the paramedics identified themselves and only 54% communicated information regarding allergies (Javidan et al., 2020). Finally, there was a notable difference between the trauma team's and paramedic team's opinion on the quality of the patient handover briefing. The nurses and trauma leads scored the briefing significantly lower than the paramedics.

Finally, paramedics are frustrated with the increasing length of offload times(Pasma, 2020). This increased time to transfer a patient to the care of hospital is called offload delay. This delay is caused by overcrowded emergency departments with high inflow of patients and not enough staff and hospital beds(Pasma, 2020). Offload delay reduces the numbers of available ambulances within a given jurisdiction. In rare, but increasingly occurring situations all of the ambulances of a city are tied up at various hospitals. This situation is called various names depending on the city but Code 0 is one name for this situation (Pasma, 2020).

2.1.3 User Observation – Activity Mapping

It is important to understand what the target users are experiencing while they move through their day. Due to the sensitive nature of this project's topic and the complications still posed by the COVID-19 pandemic, it was difficult to set up an in-person user observation.

Method

Fortunately, the paramedic industry has been idolized by the public, for good reason, which has prompted media producers to create online content following the life of paramedics. This digital avenue has created a small, mildly dramatized, window into the lives of paramedics around the world. Therefore, a combination of input from the projects advisor and insight gained from digital content (ItsBandage, 2016; Real Responders, 2020a, 2020b; Really, 2021) the empathy map found in Figure 3 displays the thought and feeling of the project's persona, Bernard.

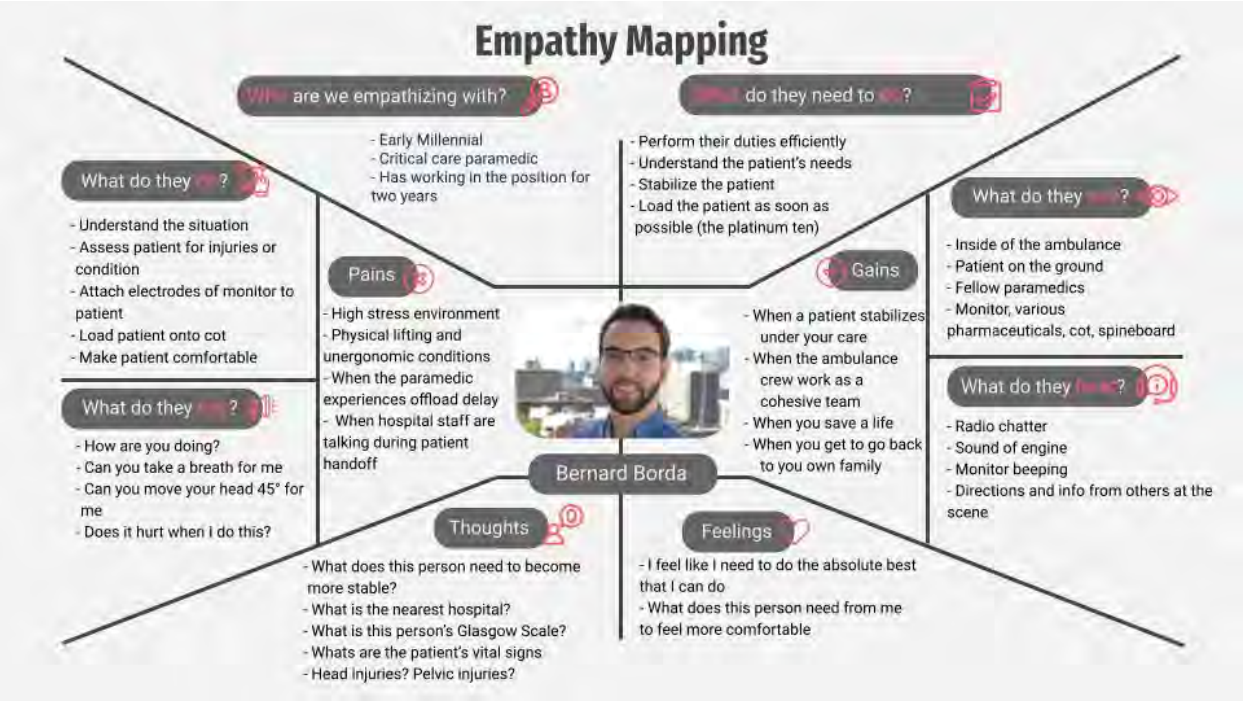


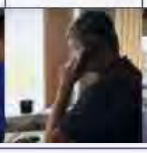
Figure 3 - Empathy Mapping of Bernard Borda During a Typical Day

Both the Empathy Map, Figure 3, and the Journey Map, Figure 4, follow paramedics through a single patient call. The basics of the call are as follows:

1. Travel to the patient
2. Assess the scene
3. Learn the mechanism of injury (if possible)
4. Stabilize the patient (if needed)
5. Load the patient into the ambulance
6. Travel to a receiving trauma center
7. Offload patient (including a briefing)
8. Record or chart all details of the patient transfer for future reference

It is important to realize that each call is different and may require a slightly different process. It is also important to acknowledge that some paramedics work from a base and others use the ambulance as workspace, even during periods of standby.

Journey Mapping - Day in the Life

	Planning	Preparation	Task 1	Task 2	Task 3	Task 4	Task 5	Goal	Completion
User Goals	Ensuring Ambulance is **Stocked**	Receiving **Call to Action**	**Travel** to **Scene** or **Hospital**	**Survey** Scene	**Extract** and **Monitor**	**Stabilize** and Warm	**Prepare for transport**	**Transport Patient**	**Hand Off** to Hospital Staff
User Actions	Use checklist to ensure all supplies are stocked in ambulance	- **Receive call** from dispatcher - **Gain initial knowledge** through dispatch - Don overalls	- Help **navigate** - Keep an eye out for **obstacles**	- Survey the scene for **clues** and **possible danger** - **Talk** with bystanders and EMS to gain insight	- **Move** the patient to **safety** - **Monitor** for signs of rapid decline in patient condition	- **Reassure** patient - Deliver **medication** - Address **urgent symptoms** - Provide **blanket**	- Support patient's **spine** - Move patient onto **stretcher** - Strap in - C-Collar	- **Walk patient** over to ambulance - **Load** into ambulance - **Standing/sitting** and leaning over patient	- Unload patient - Wait with patient for nursing staff - Provide a **brief** for medical staff
User Thoughts	I don't want to think about stock levels on call	- **What** is situation - **Where** is it - What can I expect	- How do we get there - Where to park	- What happened - **Cause of injury/illness** - **Danger?**	- Lets get **patient to safety** - How are the **vital signs?**	- The patient is **shivering** - Let's ease the pain with **meds** - **bleeding (?)**	- Be careful of the **neck** - What is the best **path** - Do we have everything	- Ok let's get this person in the air **quickly** - This setup is so **unergonomic & uncomfortable**	- What do I need to **convey** to the medical staff
Storyboard									

User Experience

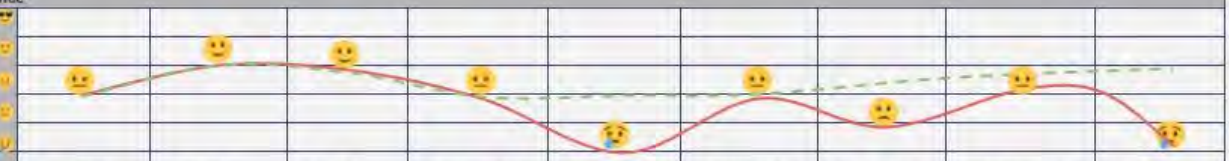
	Planning	Preparation	Task 1	Task 2	Task 3	Task 4	Task 5	Goal	Completion
User Experience									
Challenges	Ensuring that nothing is missed	- Must rush - May not get all the info	- Finding a place to land - Avoiding things	- Environmental factors - Receiving clear information	- Not being able to do anything until patient is extricated	- Management of bystanders - Stabilizing patient	- Coordinating everyone - Immobilizing head	- Long walk back to ambulance - Coordinating people	- A lot of busselling - Waiting for equipment
Takeaways	Being prepared is valuable	More info upfront the better	Flying is a team effort	Paramedic must filter the flow of information	Patient may be out of reach for a little	The human touch is important	Preparing takes multiple people & time	Workstation can be redesigned to aid paramedic	Information Transfer Important

Figure 4 - Journey Mapping of a Single Call and Accompanying User Experience Map

In Figure 4 the red curve represents the paramedic's actual experience while the green dashed line represents a preferred experience as a resultant of a new product. There are three major dips in the user's experience. The first dip corresponds to the paramedic needing to wait for a patient to be removed from a wreckage to properly assess them. The second dip corresponds to the paramedic needing to perform crowd control and manage multiple people to properly prepare the patient for transportation. While this is far from the case in every scenario it can be needed in the

populated or severe cases. Finally, a significant dip occurs when the paramedics are forced to stay at the hospital for hours with the patient, waiting for a bed to become available.

2.1.4 User Observation – Human Factors of Existing Products

Product design revolves wholistically around humans, including their physical and mental needs. Therefore, it follows that the physical dimensions of a product be tested against known standards of human proportion. This is especially true when products are intended to be used in the medical industry. Furthermore, the equipment used by paramedics further constrains product dimensions. The following ergonomic study will investigate ergonomic factors relating primarily to patient needs; however, the ergonomic needs of the attending paramedic must also be considered. This is especially true for the chest-mounted camera used by the paramedic and the lessening of cables. Rough 1:1 scale ergonomic models were constructed to explore and refine the physical dimensions of the product. Human test subjects representing various percentiles of the human figure interacted with the ergonomic models to prove and refine the design. Four components of the product solution were analyzed: Smart Mattress, Smart Blanket, Mattress Docking Platform and Paramedic Recording Vest. The insight contained in the following sections are a summarization of the ergonomic study.

Literature Review

Ergonomic studies have become a staple in the product design process. Alvin Tilley and the Henry Dreyfuss Associates provided a standard reference with the published book *The Measure of Man and Woman* (2002) which is often used in human-centred design. Paramedics must transport almost any human that could be injured, which consists of a wide range of people. For this reason, a broad range of statures were considered. Figure 5 displays the 99th percentile male stature as described by Tilley (2002). The 99th-percentile male has the widest shoulders and tallest stature of all the figures considered in the design.

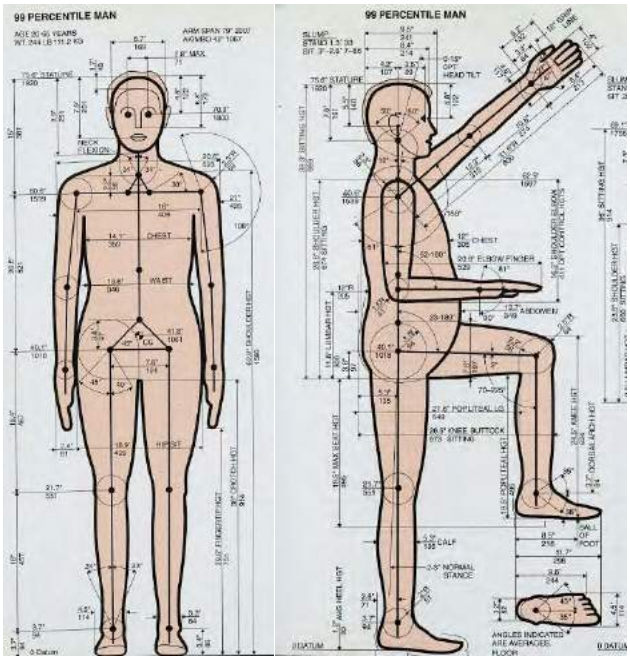


Figure 5 - Diagram of 99th Percentile Male Figure from the Front and Side View (Tilley & Henry Dreyfuss Associates, 2002)

Figure 6 displays the first percentile female representing the smallest adult patient to be carried on the stretcher.

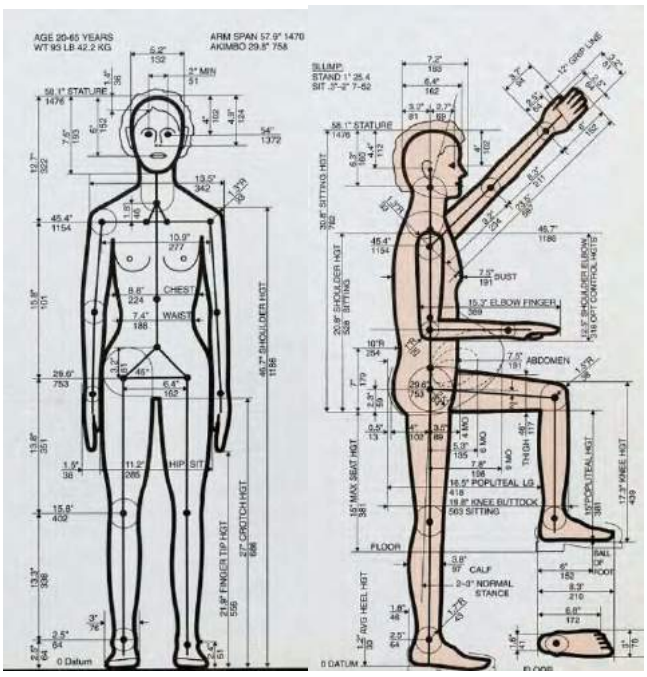


Figure 6 - Diagram of First Percentile Female Figure from the Front and Side View (Tilley & Henry Dreyfuss Associates, 2002)

The range of motion of the patient is minimal while occupying a stretcher/cot. Therefore the study of patient ergonomics focuses on comfort, position of vital organs and ability to orient the patient into a variety of standard positions. See Figure 7 for more details on the standard medical positions.

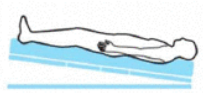
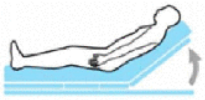
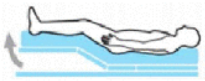
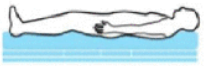
Position	Description	Image
Trendelenburg	The head of the bed is lowered and the foot of the bed is raised	
Anti Trendelenburg	The head of the bed is elevated with the foot of the bed down.	
Fowler	The head of the bed is elevated 45-60 degrees.	
Gatch	The bed adjusts a joint, allowing the knees to be flexed	
Autocontorno	The head of the bed is elevated 45-60 degrees, while a joint is adjusted to allow the knees to be flexed and legs supported.	
Lateral	The bed tilts to the left or right deviating from the medial plane	
Standard	The bed is in its initial shape, allowing the patient to lay down in a neutral position.	

Figure 7 - Standard Medical Positions: Stretchers Tend to only Perform the Trendelenburg, Fowler, Gatch, Autocontorno and Standard positions (Onchi et al., 2016)

Besides the positioning of the patient, existing equipment needs to be considered to create compatible products. Ensuring that the new design works with several existing products increases the likelihood of more paramedic services adopting the device. According to the websites belonging to two of the major medical supply brands in North America, the cot width is limited to 18 inches while the length varies from 71 inches to 73 inches (COT DOC, 2021; Ferno Canada, 2021). This narrow mattress design is further supported by limitations of space

inside of the ambulances. This is visually represented by Figure 8 where the space between the paramedic's legs and the cot is clearly at a minimum. In both the 5th and 95th percentile the knee of the paramedic is within the space of the stretcher.

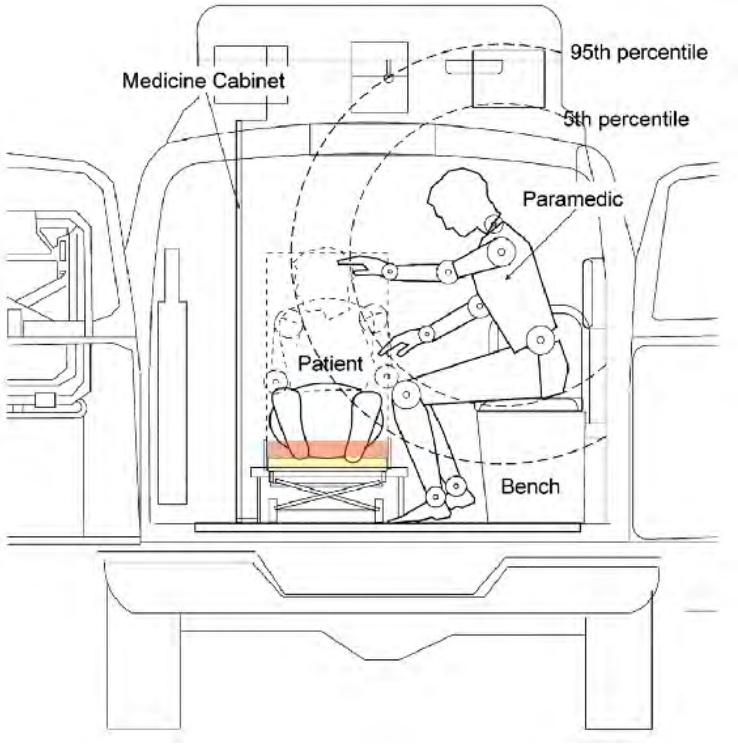


Figure 8 - Diagram of Position and Reach of Fifth percentile and 95 Percentile Paramedic (Gilad & Byran, 2007)

The smart mattress, mattress base and smart blanket all take guidance from existing medical devices and the first percentile female and 99th percentile male. However, so does the paramedic recording vest. As Guan et al. (2020) suggest, the average paramedic population is heavier and larger than the average population and so should be designed for with this in mind. Therefore, the adjustable recording vest is designed to include the 99th percentile male.

2.1.5 User Observation – Safety and Health of Existing Products

When people need medical attention, they are often in a vulnerable state. Their homeostasis has been compromised one way or another. Therefore, safety needs to be top of mind as to not further injure the patient. Biological hazards are an obvious starting place when dealing with medical supplies. Out of the 16 products that were analyzed, 6 of the products promoted their product is as easy to clean, does not absorb fluids, can be disinfected, or a combination of those three selling points, see Table 1.

Table 1 - Cleanability as a Selling Point (See Appendix C)

easy to clean	Cleanable
Easy to clean and decontaminate between uses	
easy to clean and disinfect	
easy to prevent bacterial growth	6
Will not absorb blood or bodily fluids	
no clean-up or lost equipment problems	

Another major factor is avoiding secondary injuries through uncontrolled movements of the patient's body. In both the user observation (Real Responders, 2020a) and the product bench marking, see Figure 10, body immobilization is significant. More from this table can be found in Appendix C.

Table 2 – Patient security as a selling feature (See Appendix C)

maximum motion restriction	Secure
ensure that the victim's body is secured safely;	
will not sway over obstacles or uneven ground	
secure the head ensuring patient stabilization.	
lock patients securely into place, regardless of the head shape or position.	
little risk of moving head.	8
ensure that the victim's body is secured safely;	
avoid second injury caused by disordered moving;	

Finally, ensuring the patient stays warm is something that the paramedics in each scenario of the Real Responders episode ensures. This fact has also been confirmed by the project's advisor[1],

[1] Correspondence with project Advisor, September 27, 2021 – See Appendix B

suggesting that hypothermia is a significant risk for burn victims and other patients suffering with shock or bleeding.

2.2 Product Research

Understanding what existing products are already on the market will help to discover any opportunities for new products. The following section will cover the benchmarking of existing products. This includes the functionality, aesthetics, and ergonomics of existing products.

2.2.1 Benchmarking – Benefits and Features of Existing Products

Paramedics use multiple different tools to help transport ill or injured patients to the hospital. The tool or device that is used is highly situationally dependent. Even so there are similarities between all medical products used in pre-hospital medicine. Table 3 shows a sample of the full Categorization of Benefits table which can be found in Appendix C.

Method

A variety of products were included in the benchmarking process. To compare all the products, the marketing literature was collected and tabulated. Raw benefits phrases were extracted from existing emergency medical products and tabulated. The raw benefits phrases were then clustered based on wording, or implied meaning. Finally, the number of clustered benefits phrases were tallied, and an overarching category was assigned.

Results

A sample of the Categorization of Benefits Table can be seen in Table 3. The colours of the cells demarcate each category for easier viewing. The category colours are then carried over to a summarization of common benefits in Table 4.

Table 3 - Sample of Categorization of Benefits Table (See Appendix C)

Raw Benefits Phrases	Clustering of Benefits	Categorization / Tally of Benefits
accommodate all head shapes and injury positions	accommodate all head shapes and injury positions	Accommodating
accommodates all head types and injury positions.	accommodates all head types and injury positions.	
added protection against wear and tear.	compact storage and transport	5
aid in hypothermia prevention	Fits patients 2 years and up.	
aid in hypothermia prevention	from 2 years; adults, children and infants, comfortably and securely	
all purpose transport solution.	better communication and inspection.	Inspectable (of Patient)
avoid second injury caused by disordered moving,	ensure visualization of the ears.	
better communication and inspection.	functional access for the airway;	4
blocks will not float away!	having direct access to patients ears	
can be attached to any style litter	Compact	Compact
comfort	compact size when not in use.	3
comfort	Compact, easy storage	

Table 4 - Twelve Common Benefits Found in Existing Products

Easy (to use)	14
Compatible	9
Secure	8
Comfortable (for patient)	7
Cleanable	6
Durability	6
Accommodating	5
Inspectable (of Patient)	4
Fast	4
Warming (prevent hypothermia)	4
Compact	3
Lightweight	2

Discussion

In the end, 12 distinctive benefits were found and ranked depending on the number of occurrences. Easy to use was at the top of the list with 14 occurrences. This was followed by Compatibility with other products. Compact and lightweight were near the bottom of the list, however through conversations with the project's advisor, these benefits are far more important for paramedics[1]. This discrepancy may have been caused by the products chosen for the analysis or possibly due to the wording the marketing teams chose to use.

A table of the products that were researched for their benefits and features can be found in Appendix C. The products were chosen based on the human interaction as well as their intended function.

2.2.2 Benchmarking – Functionality of Existing Products

All emergency medical equipment has a few things in common. The equipment must be easy to use, easy to clean, and cannot be the limiting factor in any enroute treatments of the patients. The following section will discuss one example a product that may cause more harm than good to a patient. This will than be followed by an example of a product that has become a symbol of great emergency medicine product design.

Method

The bulk of the data was obtained through literature reviews. Confirmation of current practices and additional information was provided by the project advisor and supported by responses from other interviewees.

[1] Correspondence with project Advisor, September 27, 2021 – See Appendix B

Rigid Long Spine Boards

The long spinal board and cervical collar combination has been ubiquitously used since the 1970s to immobilize known or suspected spinal cord injury patients. However, as of lately the effectiveness and necessity of use is being questioned by the medical community (Feld, 2018; Nolte et al., 2021). Due to the method of immobilization a patient is strapped down to a hard plastic backboard. During transport or long periods of contact, this unforgiving surface can damage skin around bony areas of the body and negatively affect respiratory function of those mounted to the board. (Feld, 2018). Long spinal boards are still used today, but in a reduce manner. Often the long spine boards are used for extraction only or critically injured patients (Feld, 2018)

Paramedicine Monitor

Both hospital and ambulances use monitors to gain insight into a patient's wellbeing immediately. However, prehospital monitors must be portable, lightweight, durable, accurate and multi-functioned and affordable[1]. For example, the Zoll X-Series Monitor/Defibrillator for EMS contains the following functionality (Zoll, 2015):

1. CPR Dashboard (helps time and track CPR activity)
2. Integrated Wi-Fi, Bluetooth, and USB cellular modem for wireless information transfer
3. Integrated Defibrillator
4. Ability to display trends
5. 12 Lead ECG
6. Oxygen Saturation and Pneumography (breathing rate)
7. Invasive and Non-Invasive Blood Pressure
8. Temperature
9. Printer

[1] Correspondence with project Advisor, September 27, 2021 – See Appendix B

Modern day monitors are also a manageable size in comparison to their predecessors[1]. An EMS monitor can now easily be carried to the site of an emergency and does not take up much room inside of the ambulance.

2.2.3 Benchmarking – Aesthetics and Semantic Profile of Existing Products

It is important to understand and align with what is socially understood as a medical product. Its also important to portray feeling of calm, hope and precision manifested within the design of the medical product.

Method

It was necessary use designs that have been vetted by industry professionals and determined to be great design. To achieve this, products catalogued by the industry recognized authority in judging product design, Red Dot, were used as inspiration and references.

Results

Figure 9 shows a compilation of selected Red Dot awarded medical equipment designs. In all cases, a white lightly textured plastic is subtly complemented by a warm grey. Touch points are sharply called out using a tasteful contrasting colour.

Figure 9 - Product Semantics of Existing Medical Devices

[1] Correspondence with project Advisor, September 27, 2021 – See Appendix B

The jury at the Red Dot Awards explains some of the key attributes of the winning designs. The jury stated that there is an “interplay of rounded edges and straight lines” (Red Dot, 2021b) as well as a “symmetry and balance… [that] radiates calmness” (Red Dot, 2021a).

Medical equipment should also have a futuristic, utopian appearance. This is as opposed to a device that looks like faded plastic from the 1990s. This will project a sense of cleanliness to the patient and paramedic as well as a feeling of confidence in the equipment. Figure 10 is an image of the Sinius dental treatment center and a winner of the 2012 Red Dot Awards.

Figure 10 - Sinius Dental Center by Sirona (Red Dot, 2012)

2.2.4 Benchmarking – Materials and Manufacturing of Existing Products

Medical equipment helps healthcare professionals treat people when they are at their worst. It follows then that medical equipment and tools are exposed to many biohazards from patients. To

ensure no disease is passed from patient to patient, the equipment must be adequately cleaned and disinfected. Unfortunately, this cleaning process can involve harsh chemicals, heat, or both(Covestro AG, 2021). Additionally, medical equipment must be robust enough to last through the ever day abuse it will be subjected to. The following section looks at some the existing materials and manufacturing methods.

Materials

This section will be split into three subsections representing the three components of the ZEROCODE system: the Smart Blanket, Smart Mattress and Docking Station.

Smart Blanket

Creating a circular economy in medicine is a difficult task due to the high-risk nature of the industry (Weiss, 2021). Many of the items used in the medical sector are labelled as single-use (Weiss, 2021). For instance, cot sheets used by paramedics are made of spun-bound polypropylene and designed to be disposed of after each use see Figure 11.

Figure 11 - Existing medical textiles are often single use (Bound Tree, n.d.)

Some reusable medical blankets, such as the hyper/hypothermia blanket by Stryker Medical, shown in Figure 12, are made of heavy-duty vinyl on both sides.

Figure 12 - Reusable Hyper/Hypothermia Blanket (Global Medical Solutions LLC, n.d.)

Vinyl is frequently used in soft medical goods as a seal for polymer foam to make it waterproof, durable, and cleanable. For instance, Figure 13 shows head blocks used to immobilize a patient's head during transportation. The head blocks are made up of vinyl-coated closed-cell foam made of a blend of polyvinyl chloride (PVC) and nitrile butadiene (NBR) (Ferno Canada, n.d.).

Figure 13 - Head Immobilization Blocks from Ferno (Ferno Canada, n.d.)

PVC is a plastic that recycles well but requires heavy metals and phthalates during its production and then can produce cancer-causing chemicals if burned during disposal (Stichnothe & Azapagic, 2013). If the PVC is combined with other materials, like in Figure 13, it may be difficult or impossible to extract and recycle.

Smart Mattress

Like the example given in Figure 13, some medical mattresses are produced by coating a plastic foam, such as PVC/NBR foam, with vinyl (Ferno Canada, n.d.). This creates an impervious soft surface that can easily be cleaned. However, again, the manufacturing and disposal of those materials are considered not environmentally friendly.

Often mattresses used on stretchers and cots are constructed using polyurethane foam wrapped in a thermoplastic polyurethane (TPU) case (Stryker Medical, 2017). The wrapping can be upgraded to a polycarbonate polyurethane blend for more durability (Stryker Medical, 2017). If the cover uses a fabric substrate, then recycling may be difficult if impossible as the two materials cannot easily be separated.

Figure 14– Fabric Cell Elite Round Saddle has a three-piece construction (Fabric, n.d.)

The three-piece design in Figure 14 is easily manufacturable, air type, and can be more easily separated into its component parts and recycled. This bicycle saddle technology can be adapted for the mattress. To adapt the saddle design to the mattress, the nylon base is replaced by a high durometer TPU so the entire mattress can stay flexible. Finally, Covestro's COV-207 Texin TPU can also be made biocompatible with skin contact (Covestro, n.d.) and can be mechanically or chemically recycled into new products afterwards (Ianelli, n.d.).

Docking Station

The Docking Station of the ZEROCODE system is like a slide-in battery charger similar to the one shown in Figure 15.

Figure 15 - DeWalt slide in lithium-ion battery charger (DeWalt, n.d.)

The Docking Station is affixed onto a paramedic's stretcher and is designed to receive and secure the Smart Mattress. The Docking Station must stand up to repeated bumps, heavy loads, sliding and disinfecting chemicals without significant wear. While the comparison is not apparent at first, athletic footwear must endure similar levels of abuse. Athletic footwear such as ski boots, soccer cleats and inline skates all need to be highly impact-resistant, wear-resistant, chemical resistant and flexible at a wide range of temperatures. Covestro's Desmopan TPU is a perfect fit for the task and can be Blow moulded into the correct shape (Covestro AG, n.d.).

Manufacturing

Like the materials section, the manufacturing section will be split up into three sections corresponding to the three components of the ZEROCODE system.

Smart Blanket

An amazing new soft technology has come out of a university in China. Luminous fibre technology has been proven by Huisheng Peng and his team at the Fudan University in China and has demonstrated that the technology can be woven into cotton (Fudan University, 2021). Therefore,

the luminous fibre can potentially be incorporated into other more medically suitable fabrics, including polyester (PLA).

Smart Mattress

Often, mattresses are manufactured out of polyurethane foams (Stryker Medical, 2017) which is produced by combining diisocyanates with polyols. When these two fossil-fuel based substances are mixed together, their reaction creates a gas that expands the mixture into a foam. However, this foam creates waste at the end of its life and has no economically sustainable method of recycling as there is little demand for the recyclate (Nikje et al., 2011). However, other companies like PURPLE make mattress that are injection molded TPU and can be ground up and remelted multiple times, see Figure 16. The TPU is formed into a grid like pattern that presumably saves material, weight and allows the mattress material to flex more freely.

Figure 16 - Purple Mattress is injected molded and can be recycled (JerryRigEverything, 2020)

Docking Station

The Docking Station comprises two pieces and is connected by nylon webbing. See Figure 17 for a view of the 3D printed sketch model.

Figure 17 - Front three-quarter view of the docking Station sketch model

Due to the thickness of the docking station and the need for rigidity at some locations and flexibility at others, the Docking Station can be likened to an automotive induction system such as the one shown in Figure 18.

Figure 18 - Air induction system produced by ABC Technologies (ABC Technologies, n.d.)

Not always, but plastic parts like the one shown in Figure 19 are often manufactured through the blow moulding process. This process can create thick, hollow plastic objects (Gemini Group, 2018). It also allows sections to be produced with flexible segments like the one on the rear section of the Docking Station (Gemini Group, 2018).

2.2.5 Benchmarking – Sustainability of Existing Products

Plastics are a marvel of human engineering because of their strength, durability, and long-lasting tendencies. However, plastics are also a major environmental hazard for the same reasons. Due to the high-risk nature of the medical industry, many items are single-use. However, some initiatives are looking to reduce the amount of waste produced by the hospital system.

There are a few ways of reducing waste from hospitals. However, there are two main directions: refurbishing single-use items and creating better networks to reuse durable medical equipment (DME).

The Association of Medical Device Reprocessors represents the global effort to acquire single-use hospital items and process them to be reused (Weiss, 2021). Not everything can be reprocessed, though; things like face masks and gloves cannot be reused. However, items like blood pressure cuffs, pulse oximeter sensors and disposable medical scissors can be reused after processing (Weiss, 2021). By repurposing single-use medical equipment, an estimated 7100 tons of medical waste could be rerouted from the landfill (Weiss, 2021). Reprocessing single-use medical equipment is a win-win situation because hospitals save money by purchasing used medical equipment for less than new equipment. This model clearly works well as the reprocessing industry has doubled in the last 20 years (Weiss, 2021).

An often-overlooked area is the waste created by durable medical equipment (DME) (Ordway et al., 2020). Durable medical equipment consists of hospital beds, walkers, powered wheelchairs, etc. (Ordway et al., 2020). This type of equipment is often discarded by its original owner even though others could reuse it (Ordway et al., 2020). Furthermore, it tends not to be broken down into its components and recycled but instead deposited in a landfill. However, recently there have been some efforts to repurpose DME in a response to our aging population (Department of Aging - Maryland, n.d.).

2.3 Summary of Chapter 2

Through various primary and secondary research methods, data was collected on the users, environments and products that interact with the paramedicine industry. The primary, secondary and tertiary users of products within the paramedicine industry are: First, Paramedics, Second, patients, third, trauma/emergency department nurses. A persona single persona was created around the primary user group (paramedics).

While a medical emergency can happen anywhere in the world, there are a few places where paramedics operate more frequently. Those places include the inside of an ambulance, a hospital's emergency department and to a lesser extent, sports facilities, swimming pools and ski hills. Within the most used space, the ambulance, space is at a premium and higher percentile people may find the space between the crew bench and stretcher to be cramped at times.

The products that are used on the market can vary depending on the application, however, many of them share similar traits, features, and benefits. For instance, medical products need to be ease to use, ease to clean, secure for the patient and not obstruct the view of the patient or hinder there medical treatment

Aesthetically, it is important to adhere to at least a few design semantics to ensure both the medical professional as well as the patient feel comfortable and confident that the device is capable of helping their situation. Examples of existing, award winning designs demonstrate that whites and off-whites coupled with light to mid-tone greys follow the current medical device aesthetics. Additionally, touchpoints are coloured in a single, bright but slightly muted accent colour.

Finally, the materials used by existing products are currently not as sustainable as they could be. The use of combined chemical polyurethanes (PU) versus thermoplastic polyurethanes TPU make the existing materials difficult to recycle. This is compounded by the addition of fabric as a substrate. Finally, blankets are designed to be single use rather than washable.

CHAPTER 3 Analysis

3.1 Analysis - Needs

Paramedics must be able to operate in a variety of locations and accommodate almost any person. It is also vital that paramedics protect their mental and physical health while on the job. According to Reichard et al. (2017) paramedics are three times more likely to be injured at work than all other workers. Furthermore, they found that the leading cause of injury to paramedics was related to body movement resulting in sprains or strains (Reichard et al., 2017). To reduce the occurrence of injuries, the ergonomics of the paramedics must be analysed. Furthermore, the needs of both the patient and the paramedics must be analysed to ensure that any new products developed for pre-hospital use are ergonomically compatible with the stakeholders, and suitable for the environment of use.

Paramedics are experiencing extra pressures as the total number of calls for ambulances is rising in Ontario (Pasma, 2020). Alongside the growing demand for paramedics, there is a growing offload delay (Pasma, 2020). Offload delay is defined as any time required to transfer the care of a patient to a hospital that is longer than the standard of 30 minutes (Pasma, 2020). When multiple ambulance crews experience offload delay, it reduces the number of paramedics that are available to respond to calls. In extreme cases, all paramedic crews are tied up waiting at hospitals. When this happens, ambulance services from adjacent municipalities must be called in to assist; subsequently draining resources from the donor municipality (Pasma, 2020).

Building off the insight gained through literature reviews, existing product benchmarking, interviews and user observations, the following section explored stakeholder needs.

3.1.1 Needs/Benefits Not Met by Current Products

Based on the information gathered in section 2.2.1 Benchmarking – Benefits and Features, current medical products are easy to use, compatible with various other medical devices and can safely interact with a patient. However, looking at the Categorization of Benefits in Table 3, there were only 4 occurrences of products marketing themselves as being “fast”. Moreso, the products that do state fast operation, these products only fast at a local, singular scale. None of the products reviewed are attempting to positively affect change more globally within the system. Additionally, none of the products reviewed promoted the fact that they increase the quality of communication between the paramedics and medical staff at hospitals. However according to the study by Javidan et al., (2020), there is a lack of quality communication during the transfer of patient care.

Table 5 - Review of Categorization of Benefits (See Section 2.2.1)

Easy (to use)	14
Compatible	9
Secure	8
Comfortable (for patient)	7
Cleanable	6
Durability	6
Accommodating	5
Inspectable (of Patient)	4
Fast	4
Warming (prevent hypothermia)	4
Compact	3
Lightweight	2

3.1.2 Latent Needs

While paramedics work professionally to maintain other people’s most basic needs in challenging times. It is the product designer’s job to provide tools to the paramedic that help them

maintain their own latent needs. This section will discuss the various latent needs of the paramedics and possible direction to address those needs.

Method

Use Maslow's theory of Fundamental Human Needs as a guiding framework to analyse gathered data. Various information sources will be tapped for information such as user interviews, user observation and reports to identify the existing latent needs of a paramedic.

Discussion

As discussed in 3.1.1 the new product designed to help paramedics must bolster the quality of communication between those included in a patient's circle of care but must also hasten the offload process. Figure 19 lays out several latent needs of a paramedic on duty. A successful product must address some or all these needs.

Figure 19 - Latent Needs of Paramedic

A table can be created to match a paramedic's latent needs with the areas of opportunity of a new product, see Table 4.

Table 6 - Comparison of Innovation Opportunities to Primary User Latent Needs

Product – Area of Opportunity	Latent Needs of a Paramedic
Bolstering of Communication at Patient Offload	Feel Satisfied with their patient care and effort
	Know the outcome of their work
	Avoid task saturation (and avoid inducing it in others)
Reduce Offload Delay (Increase call efficiency)	Be organized and on top of their charting
	Feel Satisfied with their patient care and effort
	Maintain the own mental health

Mental health is especially important, paramedics must endure many taxing experiences. The project advisor stated, one of his colleagues spent their entire shift with one patient waiting to transfer the patient to the overcrowded hospital[1]. This is taxing on the mental health of a paramedic in three ways. First, the duration of time waiting with essentially a stranger can strain the paramedics. Secondly, the paramedics are aware of the other calls that are coming in, but they are not able to respond to them. Finally, in more severe cases, the paramedics are aware the patient needs immediate medical attention but is not getting it due to their position in triage. This can be stressful especially if a patient's condition begins to deteriorate while waiting.

Additionally, when a paramedic spends time explaining a patient's situation to the Emergency Department (ED) staff, alternate conversations are often happening at the same time (Javidan et al., 2020). This inevitably results in some miscommunication. This obvious miscommunication has the potential to reduce the satisfaction the paramedic feels from doing their work.

[1] Correspondence with project Advisor, November 28, 2021 – See Appendix B

Finally, all of the patient information determined by the paramedic is communicated solely through verbal communication and then the paramedic departs the hospital. This opens a gap in information as it is impossible to refer back to vital information from the scene and golden hour time frame.

3.1.3 Categorization of Needs

The categorization of needs collects a user's immediate and latent needs. It also displays some of the users wants and/or wishes. Paramedics have a physically demanding job that often requires the paramedic to exert themselves in awkward positions or were required to use excessive force (Reichard et al., 2017). See Figure 20 for a full list of immediate needs, latent needs and want.

Figure 20 - Categorization of Needs

3.2 Analysis – Usability

To effectively analyse usability, it is helpful to break it down into smaller components:

- Interaction
- Satisfaction
- Ergonomics
- Efficiency

The interaction and satisfaction of the target user can be seen in sections 3.2.1 and 3.2.2 while the analysis of ergonomics and efficiency of use can be found within section 3.3.

3.2.1 Journey Mapping

Paramedics have various roles and responsibilities during a shift. However, to effectively design for the main role of transporting ill or injured patients to a hospital, the analysis of a single call can be seen in Figure 21. It should be noted that not all paramedics have a base like firefighters. Most will use the ambulance as a base throughout the day and may drive around or park somewhere while on standby. Additionally, the intensity of a call may vary and there may be times where no extrication or waiting to access the patient occurs (Task 3). However, to design equipment properly for paramedics it is important to understand the uncomfortable situations first before looking at some of the milder cases.

Journey Mapping - Day in the Life

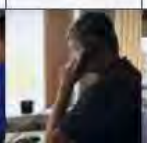
	Planning	Preparation	Task 1	Task 2	Task 3	Task 4	Task 5	Goal	Completion
User Goals	Ensuring Ambulance is **Stocked**	Receiving **Call to Action**	**Travel** to **Scene** or **Hospital**	**Survey** Scene	**Extract** and **Monitor**	**Stabilize** and Warm	**Prepare for transport**	**Transport Patient**	**Hand Off** to Hospital Staff
User Actions	Use checklist to ensure all supplies are stocked in ambulance	- **Receive call** from dispatcher - **Gain initial knowledge** through dispatch - Don overalls	- Help **navigate** - Keep an eye out for **obstacles**	- Survey the scene for **clues** and **possible danger** - **Talk** with bystanders and EMS to gain insight	- **Move** the patient to **safety** - **Monitor** for signs of rapid decline in patient condition	- **Reassure** patient - Deliver **medication** - Address **urgent symptoms** - Provide **blanket**	- Support patient's **spine** - Move patient onto **stretcher** - Strap in - C-Collar	- **Walk patient** over to ambulance - **Load** into ambulance - **Standing/sitting** and leaning over patient	- Unload patient - Wait with patient for nursing staff - Provide a **brief** for medical staff
User Thoughts	I don't want to think about stock levels on call	- **What** is situation - **Where** is it - What can I expect	- How do we get there - Where to park	- What happened - **Cause of injury/illness** - **Danger?**	- Lets get **patient to safety** - How are the **vital signs?**	- The patient is **shivering** - Let's ease the pain with **meds** - **bleeding (?)**	- Be careful of the **neck** - What is the best **path** - Do we have everything	- Ok let's get this person in the air **quickly** - This setup is so **unergonomic & uncomfortable**	- What do I need to **convey** to the medical staff
Storyboard									

Figure 21 - User Journey Mapping (ItsBandage, 2016; Real Responders, 2020a, 2020b)

3.2.2 User Experience

Continuing from the journey mapping analysis in section 3.2.1, the user's experience at each task. Again, the journey follows a paramedic from start to finish of one single call. Often there will be multiple calls throughout a single shift and so the user's experience may cycle through this pattern multiple times. Although each call will carry with it different user experiences depending on the type of call, if there is a large net negative outcome after each cycle a buildup of stress may occur.

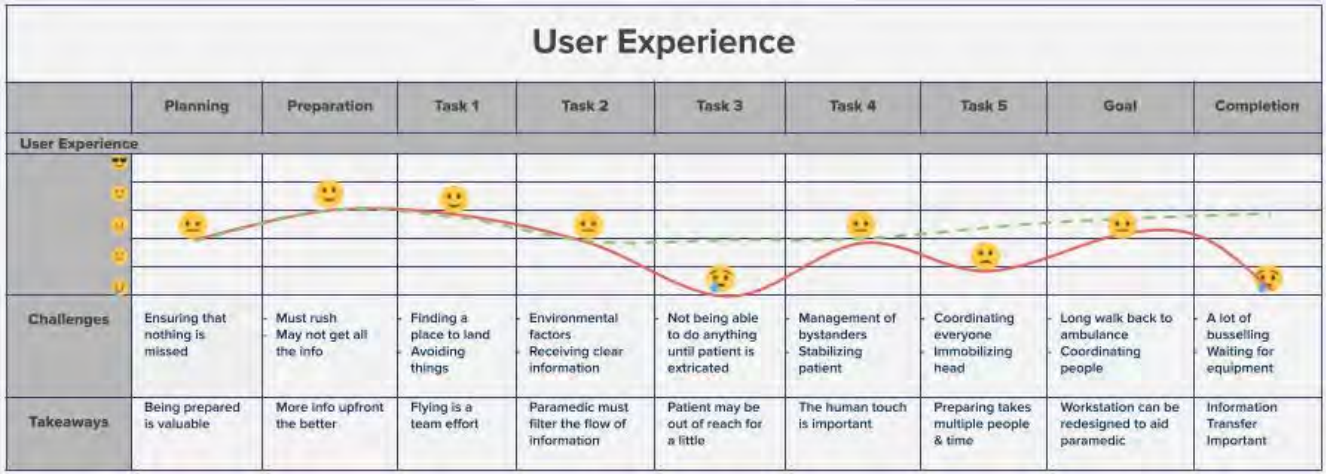


Figure 22 - User Experience Throughout the Studied Journey

In Figure 22 two lines sit a top each other. The red line represents the current user experience trend while the green dashed line represents a target user experience. It can be seen in Figure 15 that there are three significant valleys in the red line. One valley occurs during Task 2, where the paramedics must stand back and allow the patient to be extricated or otherwise moved to a safer location. This dip the user experience is caused by the inability to immediately help the patient. Although this may be taxing, this negative occurrence is out of the scope of this project. However, the negative experience shown at the completion of the task represents the excessive wait times associated with the offload delay, common in Ontario and other places in North America. The scope of this project is specifically targeting the negative experience at the end of most calls. It also encompasses the communication aspects during the transfer of patient care and the reporting and charting that is part each call.

3.3 Analysis – Human Factors

To fully understand and analyze the required human factors two dimensional and three dimensional exercises were performed. Two-dimensional exercises included activities such as a product schematic diagram and configuration diagram. Three-dimensional exercises included the designing and building of a 1:1 scale ergonomic buck. This section outlines the method and findings from both the two-dimensional and three-dimensional analysis tools mentioned above.

3.3.1 Product Schematics – Configuration Diagram

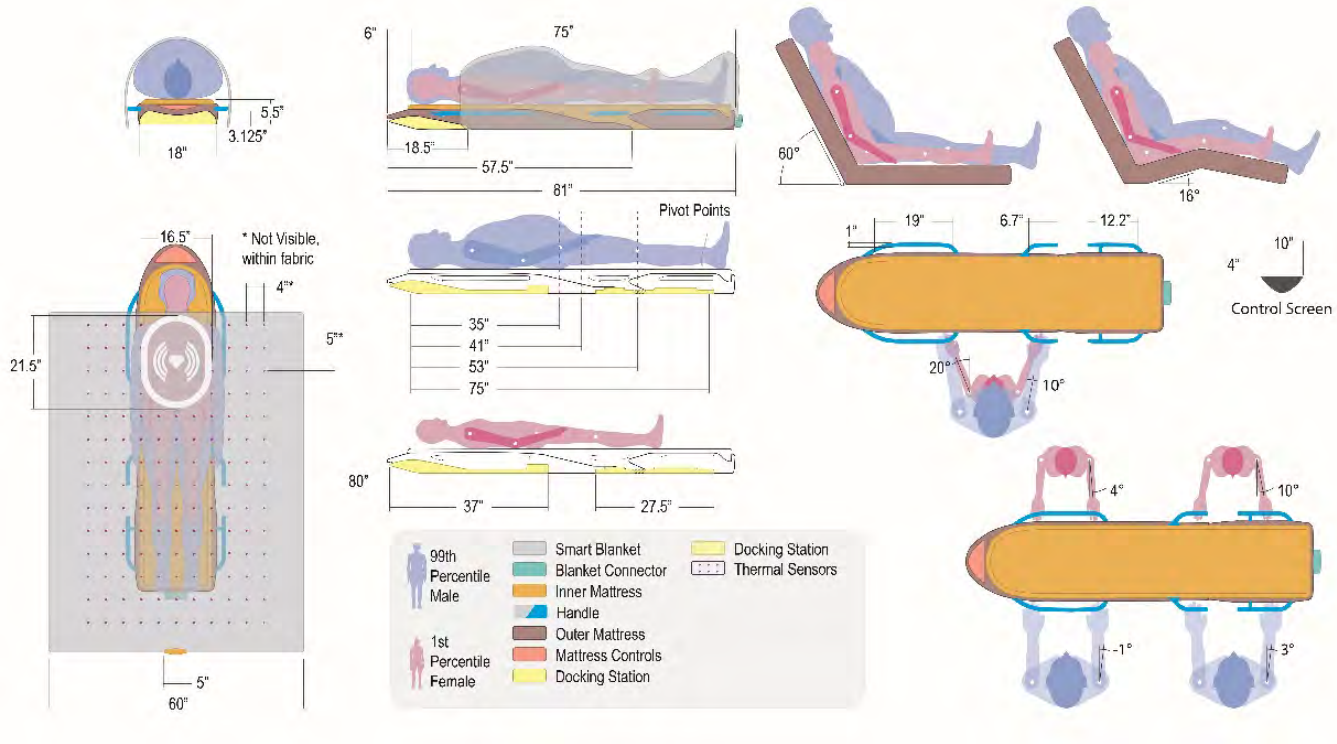


Figure 23 - Configuration Diagram

3.3.2 Ergonomic – 1:1 Human Scale Study

Sketching and anthropometric diagrams can help develop a good initial understanding of a products intended shape and size. Eventually, life size scratch models need to be constructed to develop a deeper understanding of how a product will interact with the human body.

Methodology

The ergonomics study was divided into two sections. One section was dedicated to the Smart Mattress and Docking Station while the second section focused on the paramedic's recording vest and smart blanket.

Smart Mattress and Docking Stations

The intention of studying the Smart Mattress and Docking Station was to understand the required pivot points of the stretcher to properly achieve all the necessary standard medical positions while being comfortable for the widest range of patients. The Docking Station was represented by pink foam blocks and consisted of four adjacent sections allowing for an articulation of the mattress. The mattress was represented by a continuous piece of corrugated cardboard. See Figure 24 for a view of the basic setup and construction of the 1:1 scale model. Note that the docking station is constructed from pink foam while the mattress is simply represented by a continuous piece of cardboard.

Figure 24 - A Measurement of the Knee Bend and Basic Construction (7.5" High)

The sections of the mattress were manually articulated into the approximate angle required for each Standard Medical Position. Study subjects, who were chosen to represent certain percentiles, laid on the mattress to study the interaction between the ergonomic model and their bodies. The entire length of the mattress is 75 inches, 2 inches longer than the current production models of cot mattresses. This extra length adds a more comfortable support surface for taller individuals. This added comfort is necessary as the smart mattress is designed to stay with the patient for a longer period. The extra length also negates the need for a separate headrest on stretchers. The length of each section of the docking station was chosen to maximize the range of people that could comfortably use the mattress. Table 5 displays the length of each section. The letters in Table 7 correspond to the letters in Figure 17.

Table 7 - Basic Dimensions of Docking Station

Section Letter	Location	Length
A	Torso	35”
B	Seat	6.5”
C	Thigh	12”
D	Lower Leg	21.5”
Total Length		75”

Figure 25 - Sections of the Docking Station

Smart Blanket and Recording Vest

The Smart Blanket and Recording Vest are like the Smart Mattress in that one size fits all. However, they were tested separately from the mattress. The Recording Vest body and straps were constructed from heavy paper while the camera/microphone/speaker and battery pack were

constructed from a disk of pink foam. A printed picture of an iPhone camera was pasted on the pink foam camera body to mimic the look of an advanced camera, see Figure 26. The vest was worn by a male (~75th percentile) and female (~75th Percentile) volunteer to check the fit.

Figure 26 - Example of Vest Being Warn by Female Study Subject

The Recording Vest had four adjustable straps, two shoulder straps and two underarm straps. These straps were adjustable in real-time.

The Smart Blanket was constructed from an old sheet and the ECG leads were mimicked by a few pairs of wired earbud headphones. The blanket must be large enough to fully cover the largest male with an abdomen measuring 13.7” (T) thick abdomen and 20.6” shoulder width. The minimum length is 41” however for comfort’s sake the blanket was designed to be 60”. When a human is approximated to be an ellipse, then the minimum length (L) of the blanket can be found using the perimeter (P) of the ellipse using the following equation. **IT SHOULD BE NOTED THAT THE VEST DESIGN WAS LATER DROPPED FROM THE SCOPE OF THE PROJECT.**

$$L = \frac{P}{2} + T$$

The blanket was tested two different ways: wrapping about the body and draping over the body. See Figure 19 for more details. Additionally, the Smart Blanket has built-in ECG leads that needed location testing.

Smart Blanket Tested Two Different Ways: Draping and Wrapping

Figure 27 - Smart Blanket Tested Two Different Ways: Draping and Wrapping

Results

The results will be broken into three sections: Smart Mattress/Docking Station, Paramedic Recording Vest, and Smart Blanket. Each section will describe the study subject and the models in reference to standard anthropometric data from *The Measures of Man and Woman* (Tilley, A. R., & Henry Dreyfuss Associates, 2002).

Smart Mattress/Docking Station

~50th Percentile Female

~50th Percentile Male

~99th Percentile Male

Figure 28 - Test Smart Mattress/Docking Station in supine position

As can be seen in Figure 28, all study subjects fit within the dimensions of the mattress in a supine position with no significant protruding of any limb past the mattress edge.

~ 50th Percentile Female

~50th Percentile Male

~99th Percentile

Figure 29 - Test Smart Mattress/Docking Statio in Fowler Position

As can be seen Figure 10, all study subjects can fit comfortably in the Fowler position with a knee gatch. The largest participant displayed some signs of compromise as the thigh and knee extend above the mattress due to a short section C.

Paramedic Recording Vest

Left: 75th Percentile Female; Right 75th Percentile Male

Left: 75th Percentile Female; Right 75th Percentile Male

Figure 30 - Testing Recording Vest on both male and female subjects

Left: 75th Percentile Female; Right 75th Percentile Male

Figure 31 - Arms raised position with recording vest, male and female

Figures 30 and 31 show the adaptability of the Recording Vest design. This includes accommodating women with a large bust. The four adjustable straps allow the camera and battery sections to be placed comfortably on the body. The Flexible front chest plate can conform to the contours of the body.

Smart Blanket

Left: 75th Percentile Female; Right 75th Percentile Male

Figure 32 - Top view, fully open blanket

Left: 75th Percentile Female; Right 75th Percentile Male

Figure 33 - Full-body blanket wrap

Left: 75th Percentile Female; Right 75th Percentile Male

Figure 34 - Interaction of Recording Vest and blanket with ECG electrodes

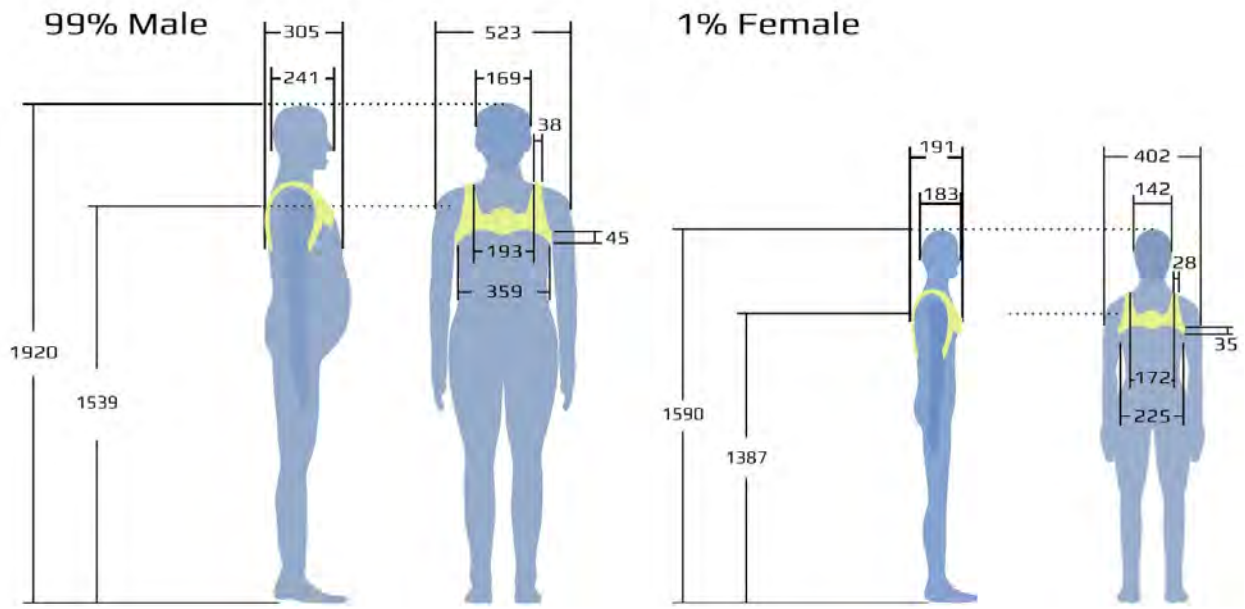


Figure 35 - Ergonomic Diagram of Recording Vest

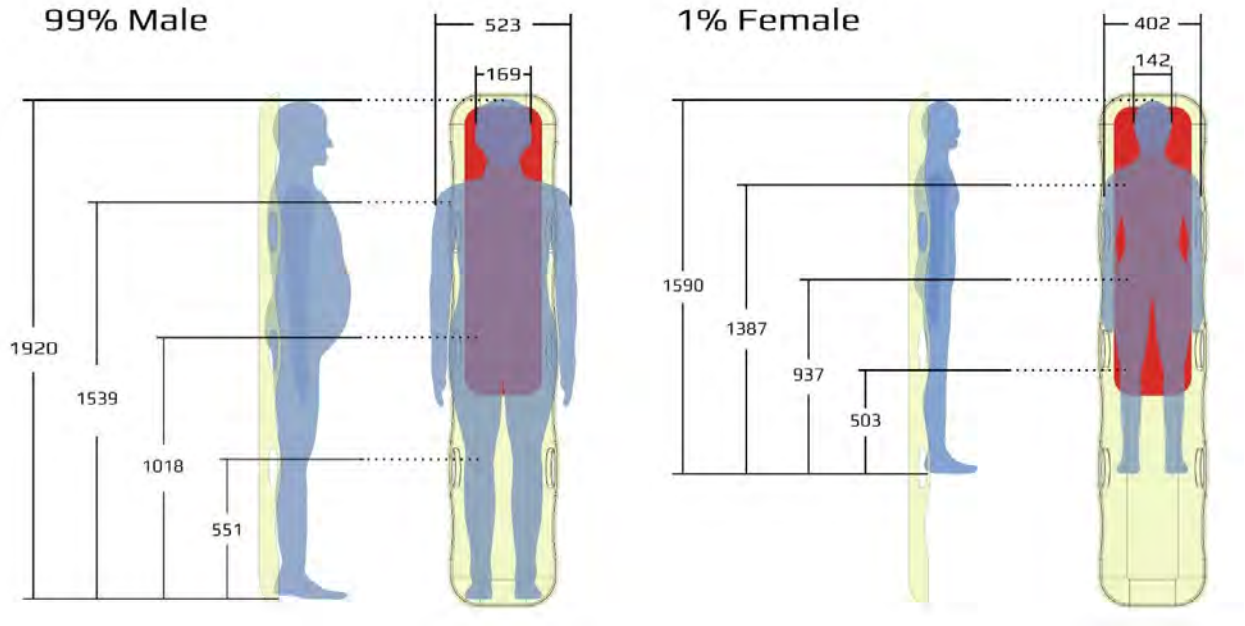


Figure 36 - Ergonomic Diagram of Smart Mattress

Analysis

From the data that was collected working with the 1:1 scale models, analysis can bring out further details. This section will follow the same format as the Results section and divide the analysis into three sections: Mattress and Docking Station, Paramedic Recording Vest, and Smart Blanket.

Sections of Docking Station

Note. A: Torso Section = 35"; B: Seat = 6.5"; C: Thigh = 12"; D: Lower Leg = 20.5" Total Length: 75"

Figure 37 - Four main sections of the Docking Station

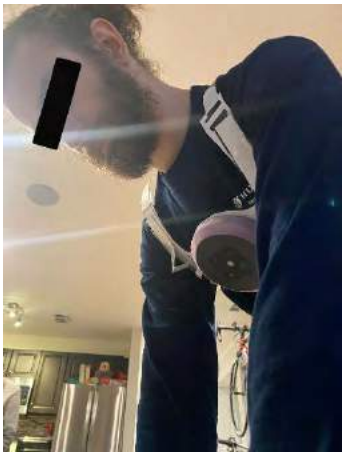
As noted in Figure 37, the Torso Length on the final ergonomic model is 35". Originally, the torso section started as 37 inches in an attempt to provide excess headroom. However, study subjects were raising concerns about their heels hanging off the mattress. The unsupported patient's foot may lead to poor circulation in the feet and possibly the loss of feeling in the feet. To rectify this issue, two inches were removed from the torso section and added to the lower leg section. This solution left just enough headroom even for the 99th percentile male while properly supporting the feet and maintaining a cot length of 75 inches.

Another modification to the dimensions involved the thigh section and the Lower leg section. In an attempt to be inclusive of the 1% female, the thigh section was made only 10 inches

long. This design, however, put unnecessary stress on the underside of the thigh for almost all other users. By transferring two inches from the lower leg section to the thigh section, less leg pressure was experienced by the study subjects.

Analysis of Recording Vest and Smart Blanket

The recording Vest fit well from the beginning. Initially, the angle of the camera was a concern due to its horizontal viewing angle. However, during a session of role-playing, it was determined that the viewing angle remains optimal due to the paramedic's need to bend over to access the patient. This bending over positions the camera directly at the patient. See Figure 38 for a patient's view of the camera.



The vest design allows for sufficient medial movement of the arms to perform CPR without obstruction

Figure 38 - Patient's View of Recording Vest

The smart blanket is sized at 60 inches by 80 inches. This size is a balance between size and material usage. This size blanket easily drapes over a 99th percentile male while laying in a supine position. The width (60 inches) is sufficient to completely wrap around the 75th percentile of both genders. However, a large 99 percentile male may find that the blanket does not completely wrap around the entire body.

Limitations and Conclusion

The 1:1 scale model testing provided large amounts of insight into the design. However, there were some limitations that may have some effect on the results of the study. First, there were no 1 percentile females available for testing. This leaves a large portion of females (50 percentile and below) untested. Additionally, there may be some other unforeseen limitations presented by the stretcher frame. Unfortunately, no stretcher was available to perform testing on. This may leave potential design interferences undetected.

Overall, the 1:1 ergonomic test was successful with sufficient insight gained. Through this testing, the dimensions of the smart mattress and docking station have been verified with volunteer patients. Additionally, the sizing, shape, strapping mechanism, and camera placement of the Recording Vest were honed.

3.4 Aesthetics & Semantics Profile

While the form and aesthetic properties of a medical product may not come to mind as the most important asset of those devices, it is an aspect that may impact the use and functionality of the product. Medical tools have a long history spanning back to Hippocrates in 460 BC when he began to scientifically study medicine (Hajar, 2015). The extensive history of medicine allowed the brewing of a rich culture surrounding medicine and the tools and instruments. While this tenure is overall very positive, it brings some difficulties; for instance, the development of the phenomenon of tomophobia or the extreme fear of medical procedures (Wodele & Legg, 2019). It then follows that an industrial designer should keep abreast of the historical, social, cultural, and psychological significance of modern medical devices.

Product semantics is the wide-ranging study of the form of human-made objects and the significance and meaning derived from the form (Krippendorff & Butter, 1984). As Krippendorff and Butter (1984) explain, designers should strive to develop a lexicon of forms that allow them to not only

connect shapes in a meaningful way but to allow those shapes to be understood by another person with little or no instruction. Additionally, a user enters a relationship with the product. As they interact with the product (and its form and surfaces), their understanding and perceived meaning of the product change (Krippendorff & Butter, 1984). With increasingly intimate knowledge of the product, further interaction will again change the meaning of the product in a reoccurring loop (Krippendorff & Butter, 1984). In other words, there is an articulated relationship between the designer and the meaning given to the product they create (Krippendorff & Butter, 1984). Still, this evolution of meaning given to a product should be estimated and planned for by the designer to reduce the risk of an unsuccessful product.

Method

To gain valid and non-bias analysis, it was necessary to study designs that have been vetted by industry professionals and determined to be great. To achieve this, products catalogued by the industry-recognized authority on product design, Red Dot, were used as inspiration and references. This is followed by a deviation from medical products and the study of vehicle and housing interiors from various sources. Additionally, a short literature review allowed for more clarity.

Results and Discussion

While medical devices are initially judged by their functionality, aesthetics do have an important role in their success as a device (Hyman & Privitera, 2005). For instance, the appearance of a medical device may subconsciously determine how a paramedic handles an instrument; for example, does it look rugged, fragile, precise, clean (Hyman & Privitera, 2005)? Furthermore, it may determine how a patient interacts with a device, for example, a child fiddling with a fun-looking device (Hyman & Privitera, 2005). Studies have shown the potential effects on healing by the environment a patient recovers in (Ulrich, 1984). The study by Ulrich (1984) involved the progress of recovering surgery patients and found that a view of nature through a window positively impacted the process

(Ulrich, 1984). The study suggests that the views of nature shortened the postoperative recovery time, improved the patients' mood and reduced the need for strong pain medications (Ulrich, 1984). Therefore, it is plausible that the aesthetic of medical equipment could be designed to have a similar healing effect.

Looking again at the previously benchmarked equipment from Section 2.2.3, Figure 39 shows a compilation of selected Red Dot award winning medical equipment designs. A warm grey subtly complements a white lightly textured plastic in all cases. Touchpoints are sharply called out using a tasteful contrasting coloured plastic.

Figure 39 - Samples of Red Dot Awarded Medical Design (Red Dot, 2021d, 2021a, 2021c, 2021b)

The jury at the Red Dot Awards explained some of the critical attributes of the winning designs. The jury stated that there is an "interplay of rounded edges and straight lines" (Red Dot, 2021b) as well as a "symmetry and balance… [that] radiates calmness" (Red Dot, 2021a). In addition to symmetry and balance, a design can be humanized using organic forms, demonstrated in Figure 40 by the 2012 Red Dot-winning dentist workstation, Sinius (Red Dot, 2012). For some, going to the dentist may be a stressful experience. However, the equipment does not need to perpetuate the stress.

Figure 40 - The flowing curves of the Sinius Dental Treatment Center humanize pragmatic medical equipment making the chair more approachable (Red Dot, 2012)

It is important to deviate from the medical field to see how other areas employ techniques to translate desired human moods and emotions such as calm, confidence, balance, and harmony as well as characteristics like modernity, cleanliness, and health. Figure 41 shows a selection of indoor living spaces and vehicles that portray these desired emotions.

Figure 41 - Interior Design of Vehicles and Housing as Deviating Inspiration (Finlay, 2016; *How to Create a Calming Interior: Home Decor & Design* | *KD Blog*, n.d.; Metcalfe, 2018; Silvestri, 2019)

In many of the selecting images in Figure 41, horizontal lines and a few pronounced vertical lines are interlaced with circular forms suggesting calm but attentive moods. Each image also consists of mostly soft material and forms suggesting a soft shape or surface. Muted whites and blues are mixed with earthy tones to convey stillness and a grounded mood.

Conclusion

A designer is tasked with communicating the product's intention to the user and planning and predicting the everchanging relationship between a user and a product. In the prehospital medical field, functionality and reliability always come first. However, the aesthetics and semantics of a product play a large part in how a paramedic or patient interacts with the product. In such a setting as the medical field, a product should help to set the mood of confidence, reassurance, calmness, and healing.

3.5 Sustainability – Health, Safety and Environment

The tools used by paramedics and healthcare providers should not add to a patient's malaise, cause discomfort to attending paramedics and should not cause unnecessary harm to the planet. The repetitive need for equipment while treating the sick and vulnerable encourages medical staff to utilize single-use equipment which reduces the risk of transmitting disease from one patient to another. While the risk of cross-patient contamination is reduced through single-use equipment, the environment and planet suffer. It is a difficult balancing act to create environmentally sustainable medical equipment. This section suggests the use of certain materials achieve that balance.

Health

It is essential that both the Smart Blanket and the Smart Mattress are biocompatible as they have a high chance of contacting the patient's skin.

Smart Blanket

The Smart Blanket fabric is made from biodegradable polyester or PLA fibres. Polylactic acid is considered biocompatible and biodegradable and is often used in medical applications (Carvalho et al., 2020).

Smart Mattress

The Smart Mattress is mainly constructed out of TPU. According to Covestro, there are specific formulas of TPU that are biocompatible and can contact the skin for extended periods and contact circulating blood, bone, or tissue for up to 24 hours (Covestro, n.d.).

Safety

It is essential to consider the safety of the patient and paramedic around the ZEROCODE system. This includes all three components: Smart Blanket, Smart Mattress, and Docking Station.

Smart Blanket

The Smart Blanket will encounter situations where bodily fluids will land on it. Additionally, there will be times when dangerous viruses and bacteria will fall onto the surface of the blanket. To ensure the safety of everyone, the blanket is washed and disinfected with a bleaching agent and must

last at least 50 wash cycles. For this reason, polyester (PLA) is the main material used to construct the blanket. This material can be washed and disinfected multiple times with only minimal wear (Sun, 2011).

Smart Mattress

Paramedics must be prepared for anything, and so should their stretcher mattress. Bumpy ambulance rides, seizures, and other energetic movements of a patient's body can be dangerous if they are not lying on a forgiving mattress. Therefore, the Smart Mattress is built using a biocompatible TPU. The design of the mattress accentuates the flexible nature of TPU with the pyramidal air cushion design like the Fabric Cell Elite Round pictured in Figure 42. Furthermore, the mattress must withstand constant cleaning and disinfecting chemicals to avoid any cross-contamination between patients. This is another benefit of TPU.

Figure 42 - Pyramidal bicycle saddle design from Fabric (Global Cycling Network, 2018)

Docking Station

As with the other components of the ZEROCODE system, the Docking Station must be chemically resistant to withstand constant cleaning. The Docking Station is also tasked with securing the Smart Mattress to a stretcher. It must withstand the forces exerted on it by a weighted Smart Mattress driving through traffic, constant loading and unloading and repeated impacts. Therefore, a high durometer TPU is used for the Docking Station. The high durometer TPU is stiff enough to provide and safe supportive platform for the Smart Mattress but forgiving enough to dissipate bumps.

3.6 Innovation Opportunity

As seen in Section 3.1.1 only a few benchmarked products promote increasing the speed or efficiency of the patient transfer. Additionally, some of the Primary User's latent needs are reducing the clutter around the patient during transfer, reducing the risk of task saturation. Furthermore, some of the Immediate Needs of the Primary User is being able to clean the ambulance and prepare it for the next patient quickly and effectively. Both the latent and immediate needs that were previously spoken about can be tied to the efficiency of the call. Added to this argument is the findings from Javidan et al., (2020) stating that more needs to be done to improve the communication between paramedics and receiving nurses, especially in overcrowded emergency room settings. If the existing, benchmarked products are mapped on a plot represented by the clearly defined needs that exist in paramedicine, the area of innovation becomes obvious, see Figure 43.

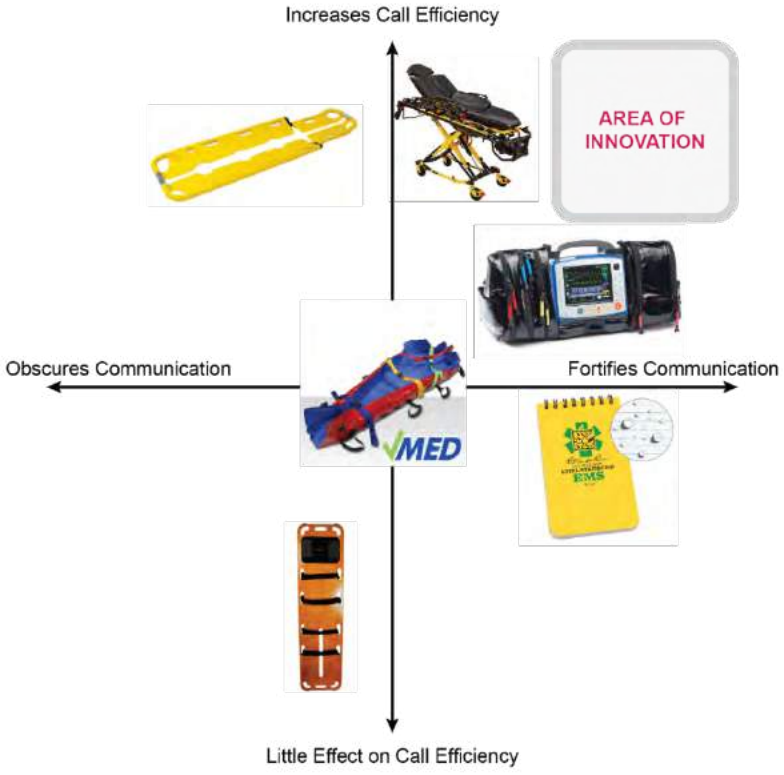


Figure 43 - Scatter Plot of Existing Project Plotted on a Communication Vs Call Efficiency Graph

Of the products that were studied, none of them fill the space in the top right corner. This area represents products that both increase the quality of communication between the paramedics and the medical staff but also actively help to increase the efficiency of the call.

3.6.1 Needs Analysis Diagram

Basic Needs				
Homeostasis	Monitors and Maintains Heart Rhythm			High
Food, water, shelter				
Pleasure, gratification (sensory, compulsive responses)	**Paramedic:** Allows paramedic to feel pleasure from **visually** seeing a patient stabilize	Slight		

Security				
Safety	**Paramedic:** Safeguards against undesired secondary shock of paramedic from defibrillator			High
State, Group, Individual				
Securing Resources	Combines multiple functions into single unit to reduce space and cost		Moderate	
	Reliability - Must always work without error or failure during call			High
	Durability - Must survive daily use in the field			High
Control (Over environmental tasks)				
Intuitive (Easy to Use)	Must be easy to understand under high stress		Moderate	
Speed (fast, less time)	Real-time monitoring, fast		Moderate	
Control (precision, responsiveness, power)	Must be precise, responsive, and accurate			High
Long Term Security/Stability of Group				
Health/care/education	Ability to train new hires on system		Moderate	
Environmental sustainability	Minimal amount of disposable items	Slight		
Proof of Procedures/Validity of Practice	Ability to record activity of paramedics to prove level of care			High

Social Belonging				
Fear of Abandonment	**Patient:** Sound of the monitor may make the patient feel like they are being taken care of	Slight		
Fear of the Enemy				
Tribal Identity	Signifies the quality and how up-to-date paramedic service is		Moderate	
Behaviour Cues for Survival (copying behaviours... safe to eat, learned skills)	How and where the monitor is stored and used		Moderate	
Behavioural Cures for Social Interaction of Group (copying behaviours... interactions cues, play, have fun)				
Peer Pressure				
Social Expectation (social covenant (gift))	**Paramedic:** May conform to the public's image of a paramedic by carrying the right monitor	Slight		

Esteem				
Social Status 'The elite have it... I want to be like them'				
Social Recognition	Within paramedic community knowledge of one monitor over another my be more beneficial	Slight		
Sexual Attractiveness				

Self-Actualization 'Higher Order' Functions/Needs Needs that are predominantly 'outer cortex'				
Intrinsic Pleasure	Fulfilling duties while interacting with a satisfying, well made device		Moderate	
Creative Endeavors				
Experiential (extrinsic)				
Experiential (intrinsic)				
Emotional				

CHAPTER 4 Design Development

4.1 Initial Idea Generation

It is often said that the design process is not linear but is convoluted often hoping around between multiple stages of the design process before a more solidified solution is developed. The process of this project was no different. Within this chapter is a synopsis of the process. The design development focused by establishing inspiration and narrowing the projects aesthetics. Mind mapping allowed for a deeper understanding of the more minute issues faced by paramedics in the field and allowed pockets of possibilities to open. Ideas were further explored and refined through sketching and then later detailed using CAD software. Scaled physical model studies helped even out wrinkles in the design and then finally, the design was showcased through a 1:5 scale model prototype.

4.1.1 Aesthetics Approach and Semantic Profile

As stated by Tuszyńska-Bogucka et al. (2020) treatments at a hospital ought to attempt to reduce or alleviate stress felt by the body and mind of patient to produce the best recovery outcomes. This same notion may extend to the prehospital environment. Tuszyńska-Bogucka et al. (2020) determined, through eye tracking analysis of emotional responses, that monochromatic visuals with minimal pops of colour were preferred over a more vibrant, multi-coloured, visuals for areas of rest and leisure. Additionally, people find that the loss of control withing the hospital system can be stressful (Ulrich, 1991), and this loss of control often begins with a ride in an ambulance.

It was imperative that the Smart Mattress, Smart Blanket and Docking Station take on a calming, comforting and almost motherly aesthetic to attempt to reduce the stress felt by a patient newly entering into the hospital environment via ambulance. The combination of blues, purples, whites and greys projects a calming aesthetic and can evoke feelings of trust, cleanliness, peace compassion and security (London Image Institute, 2020)

Figure 44 - Sink or Swim By Dana Mooney (Mooney, 2022)

Furthermore, a presence of horizontal lines brings a sense of stillness and calmness. This can be seen in the Dana Mooney painting in Figure 44. This can also be observed in the confident but subdued design of the Rivian R1S displayed in Figures 45 and 46. The R1S has a large white light band along the front and a relatively flat and horizontal shoulder line. Finally, the Disney character Baymax, shown in Figure 47, has a horizontal line with a slight concave up curvature between his eyes that alludes to a small smile or uplifted brow.

Figure 45 - 2022 Rivian R1S Near Water (Ogbac, 2022)

Figure 46 - Rivian R1S Interier Layout (Ogbac, 2022)

The Rivian R1S has distinctive pill shaped headlights that are cute and non aggressive. The softness from the headlines is also distributed throughout the cab with approachable rounded rectangles as accents in multiple locations, See Figure 46. The concepts of soft and approachable is also perfectly exemplified in the character design of Disney's Baymax shown hugging a character in Figure 22. Looking across at other products, he rounded, lovable shape of Baymax is present in the chair design by Yuan Shaoyun and Kim Taek shown in Figure 48. The curved back of the chair looks like it is hugging the user. The rounded form and deep seat appear approachable and comforting.

Figure 47 - Disney's Character Baymax from the Movie Big Hero 6 (Mynott, 2015)

Figure 48 - Physical and Sound Therapy Chair by Yuan Shaoyun and Kim Taek (Red Dot, 2020)

4.1.2 Mind Mapping

It is no secret that the medical field is complicated to understand. Finding the relationship between various stakeholders and their tools and environments can be equally challenging. Therefore, to better understand the various stakeholders, user environments, existing products, and current pain points, a mind mapping exercise was performed to visually distribute and analyse data collected through user interviews and secondary sources. Four themes were used to categorize the information: Design Considerations, Industry, Environment and User. For clarity, the categories were divided up into separate figures.

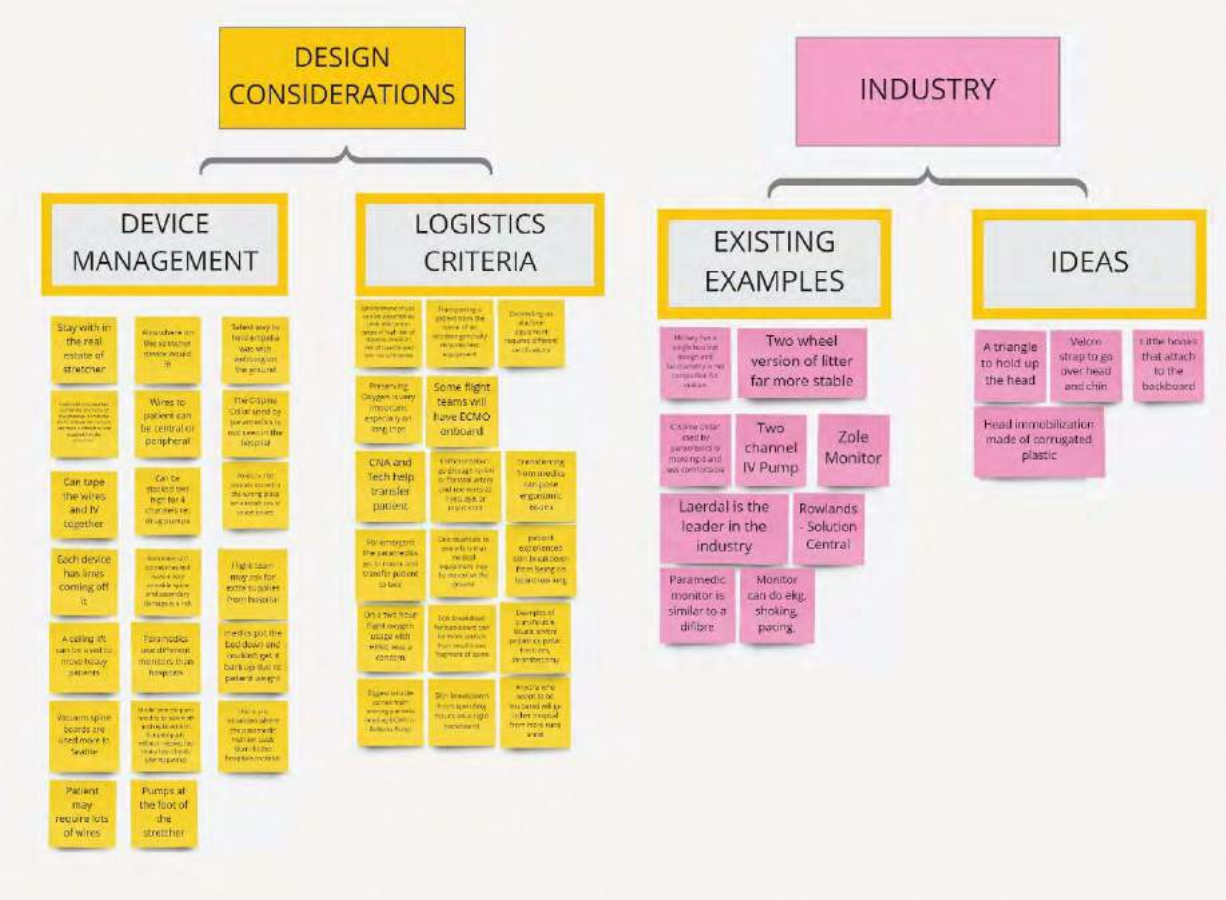


Figure 49 - Mind Mapping Categories: Design Considerations and Industry

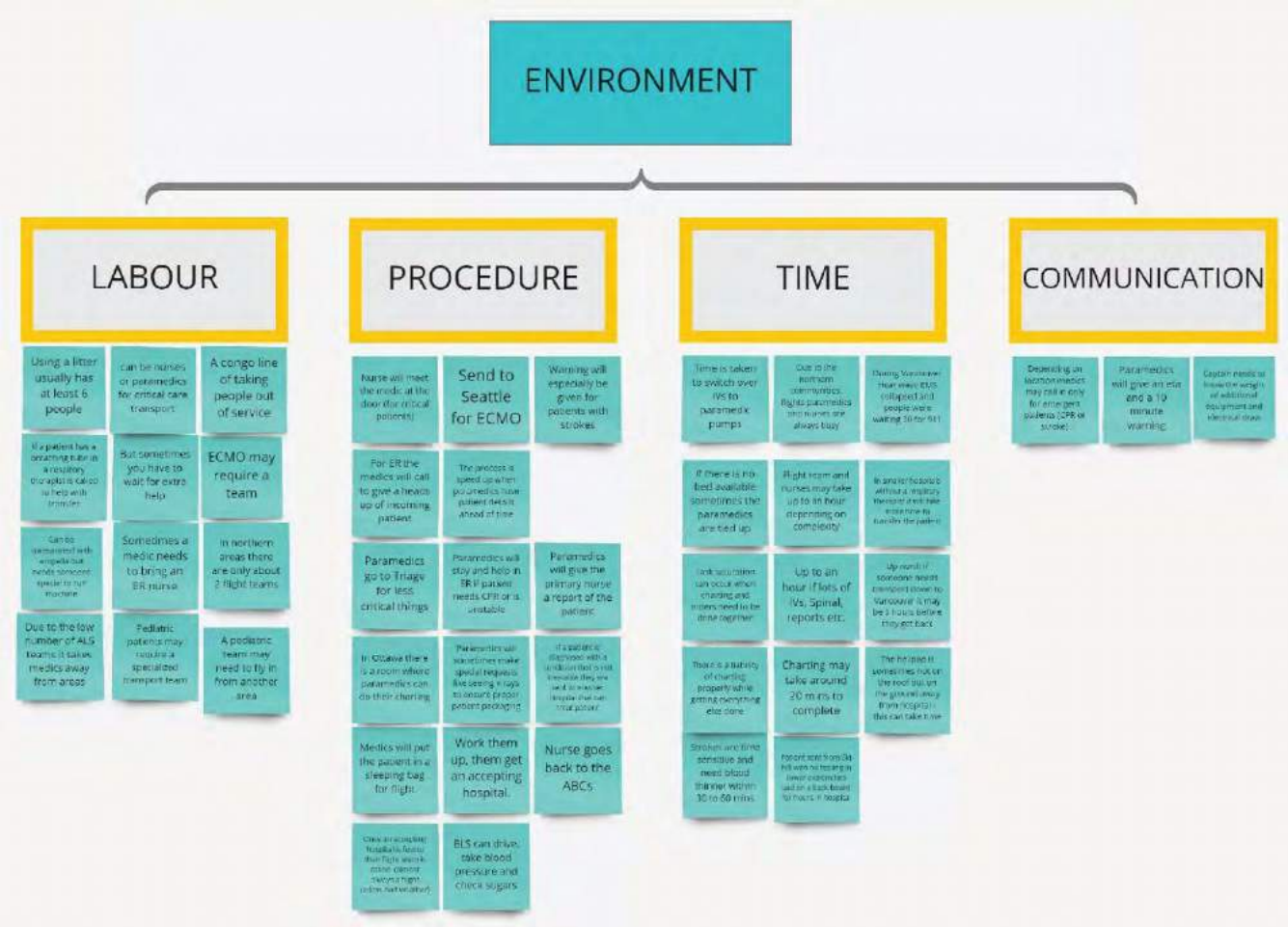


Figure 50 - Mind Mapping Category: Environment

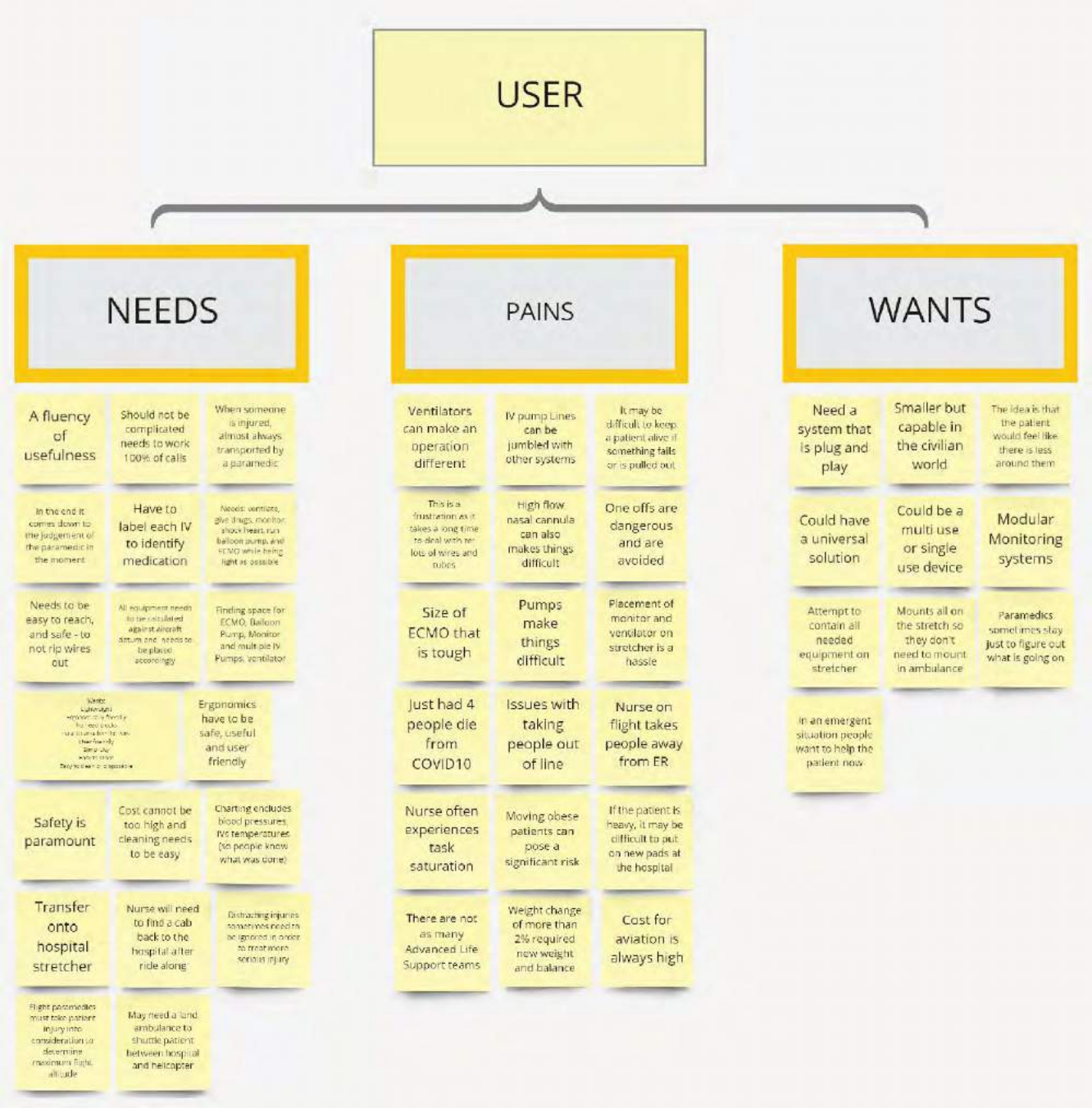


Figure 51 - Mind Mapping Category: User

4.1.3 Ideation Sketches.

A variety of ideas were explored in the beginning. Many of the ideation sketches were produced before a serious design aesthetic was established. Additionally, the original intent was to focus more on critical care paramedicine rather than a more general paramedicine approach the final design

direction took. Additionally, a fixation on helping patients with potential spinal injuries may have momentarily limited the initial exploration.

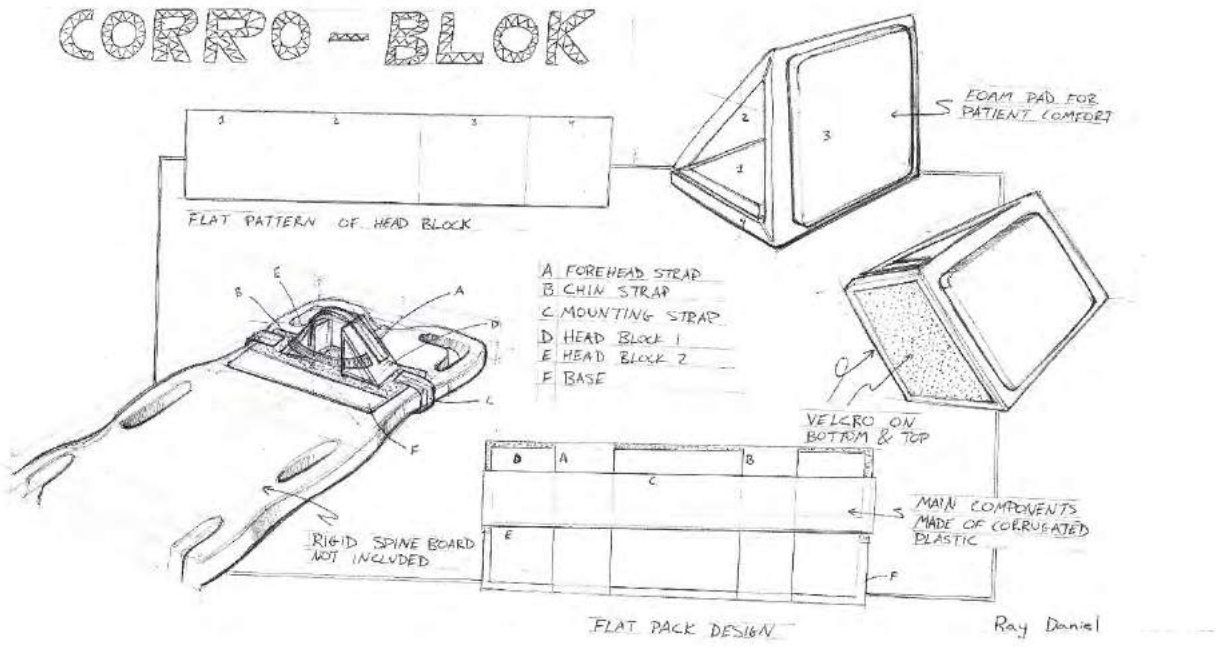


Figure 52 - Corro-Blok Head Corrugated Plastic Head Immobilization

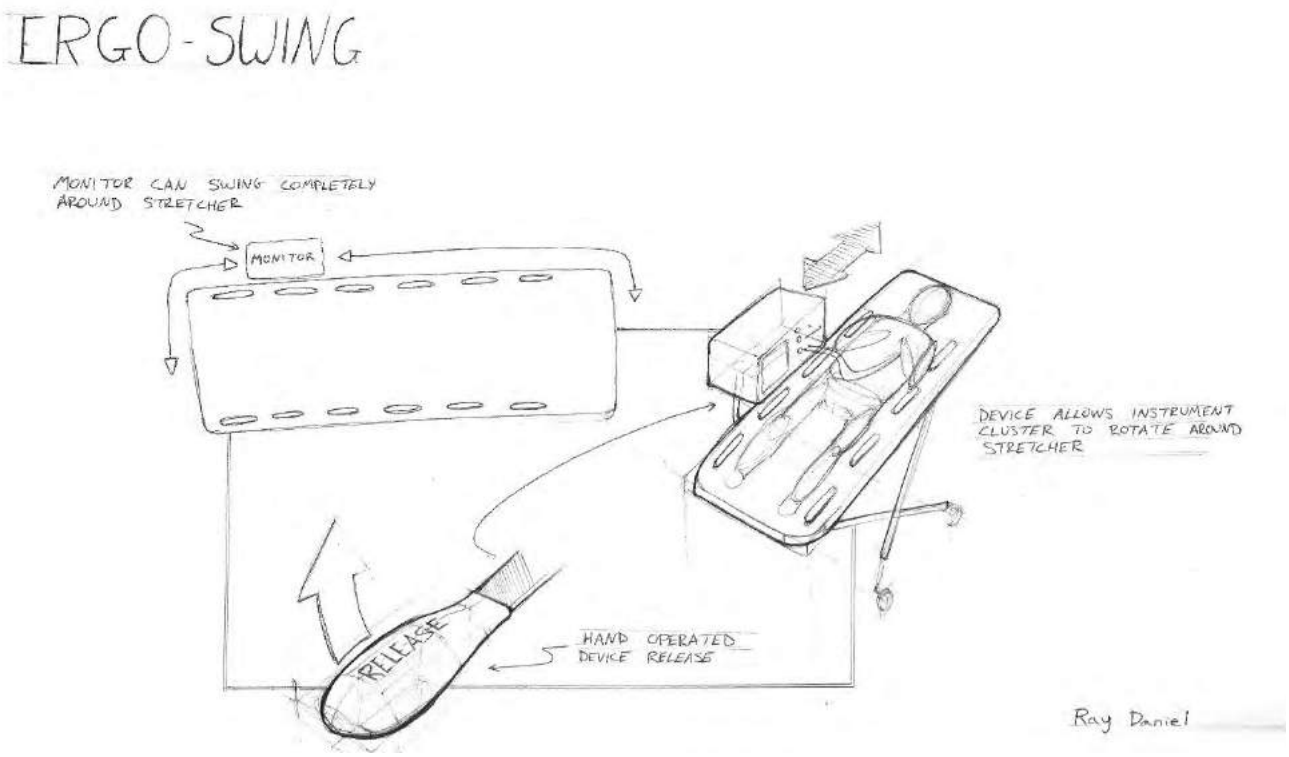


Figure 53 - Ergo-Swing Device Mounting System

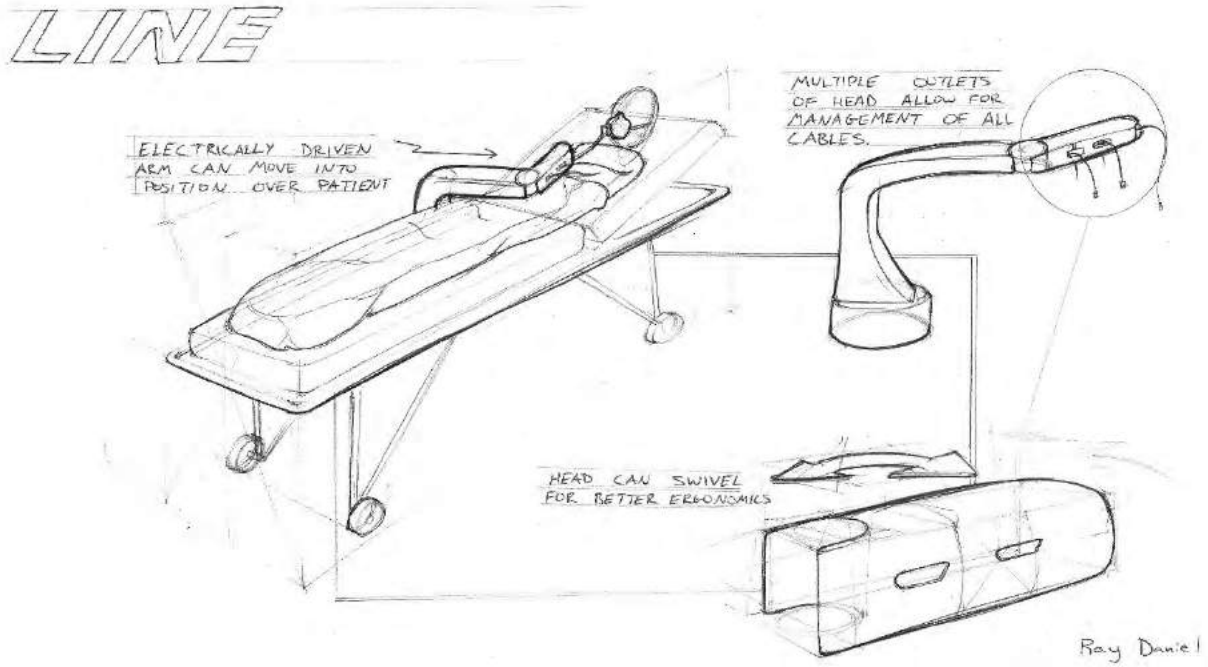


Figure 54 - Line, Tubing and Cable Management

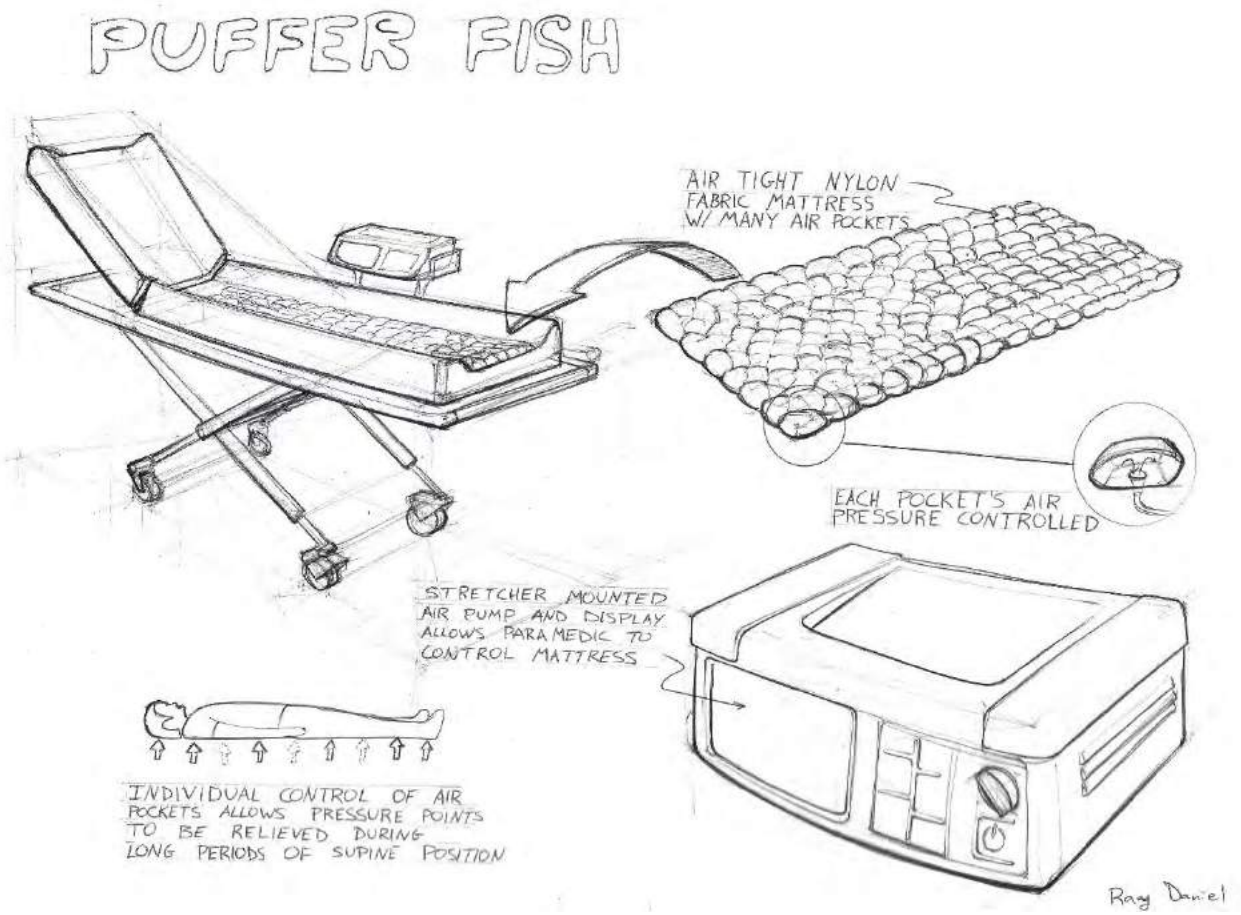


Figure 55 - Puffer Fish, Bed Sore Reduction System

4.2 Concepts Exploration

The concept exploration phase of this project was riddled with dead ends and confusion, much of which stemmed from the complexity of the topic and the narrow, extremely advanced nature of critical care paramedicine. To give a jump start to the process and build momentum, the focus on critical care was truncated to more general paramedicine. This allowed room for exploration in an arena with less high stakes events and a need for extreme precision at every step of the process. While critical care paramedicine has its challenges which require solutions, a designer with more advanced medical knowledge and experience in the field would more successfully find adequate solutions.

The following concepts deal with several issues including paramedic safety while transporting a patient, patient comfort, reduction of loose cables and information tracking.

4.2.1 Concept One

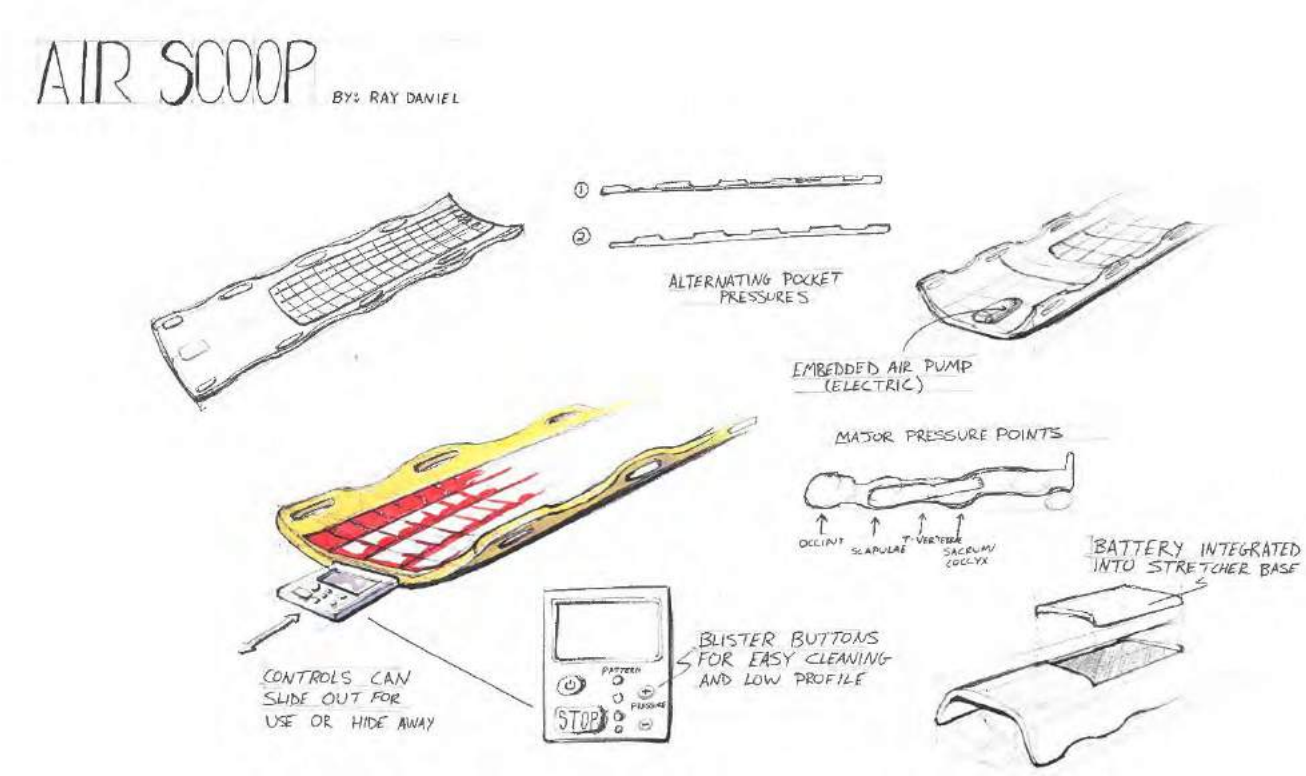


Figure 56 - Air Scoop: Patient Transfer Device

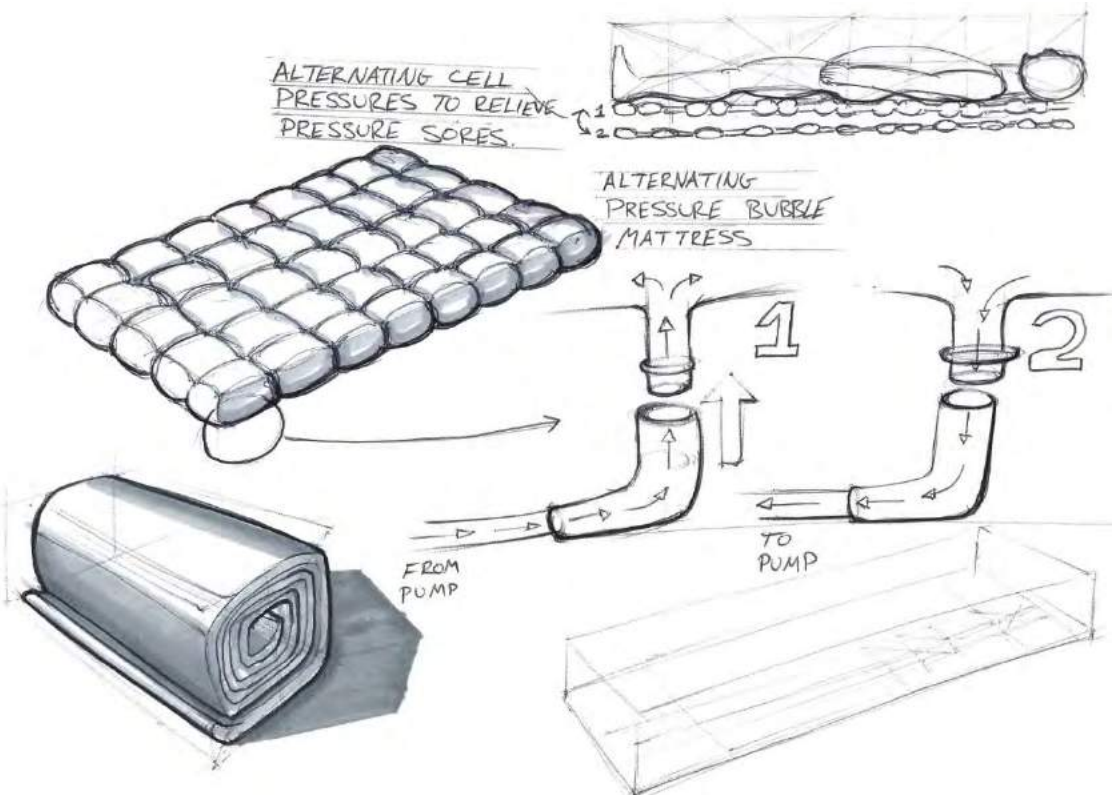


Figure 57 - Possible Workings of Bed Sore Relief System

4.2.2 Concept Two

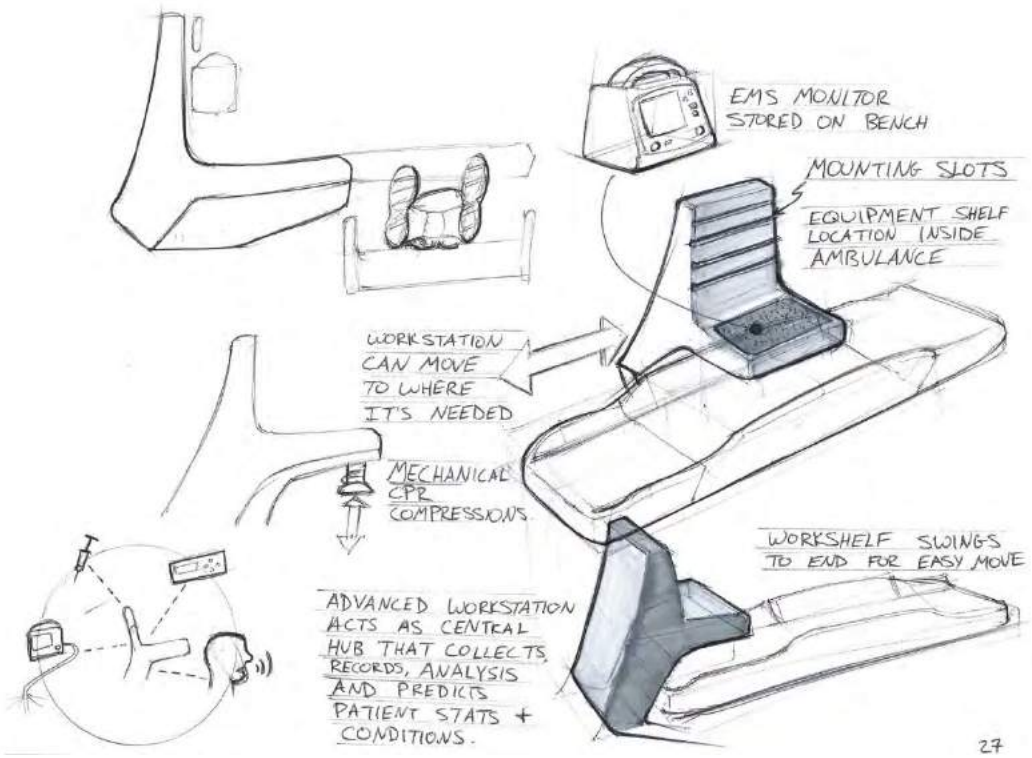


Figure 58 - Concept Development of a Swivelling Device Rack

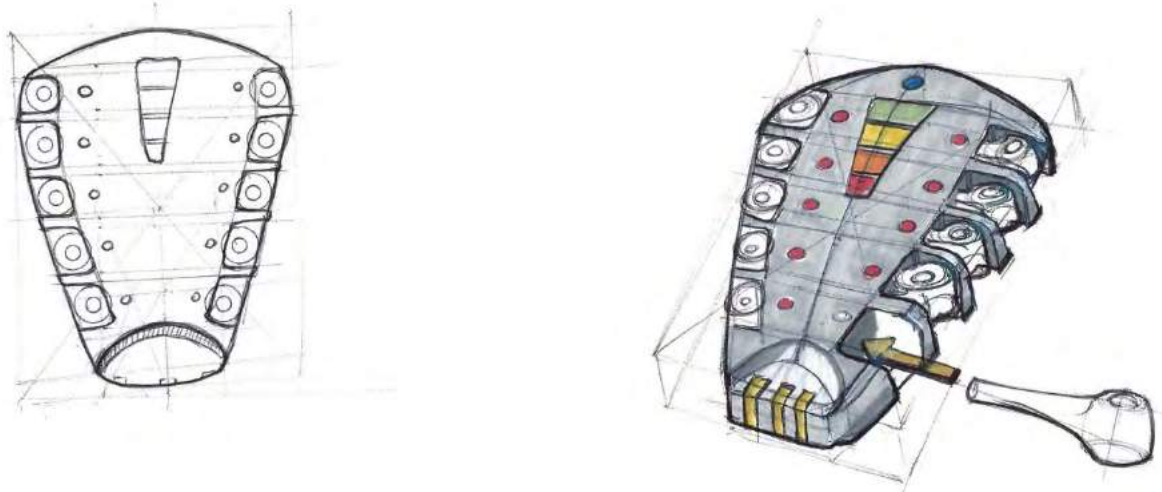


Figure 59 - Example of a Possible Wireless ECG Electrode Hub

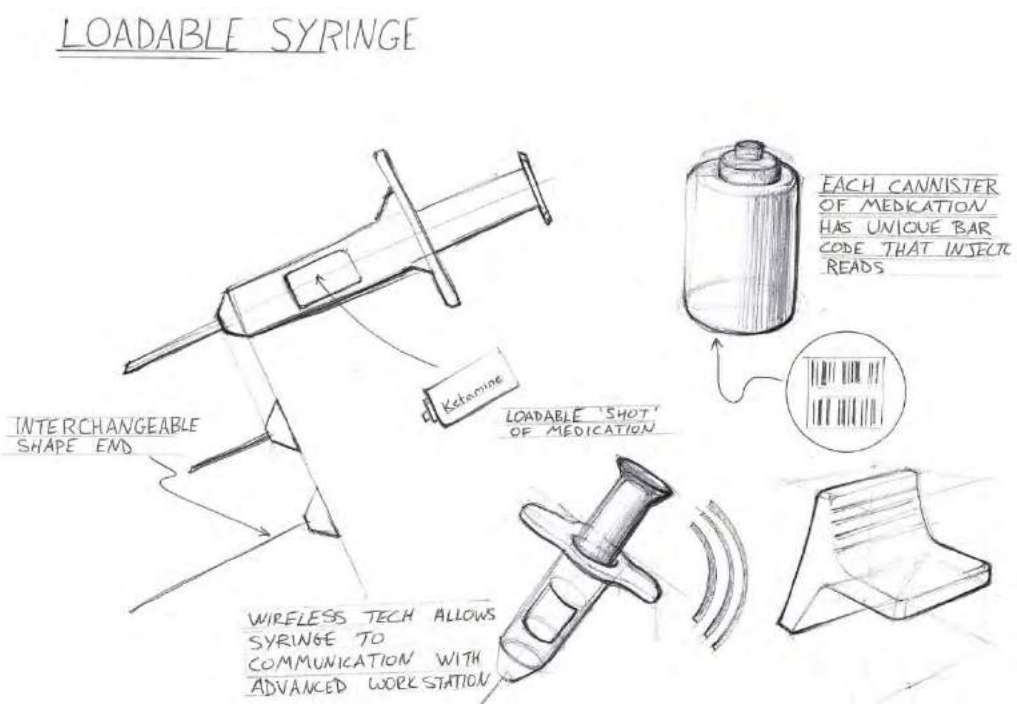


Figure 60 - Internet of Things Loadable Syringe Design

4.2.3 Concept Three

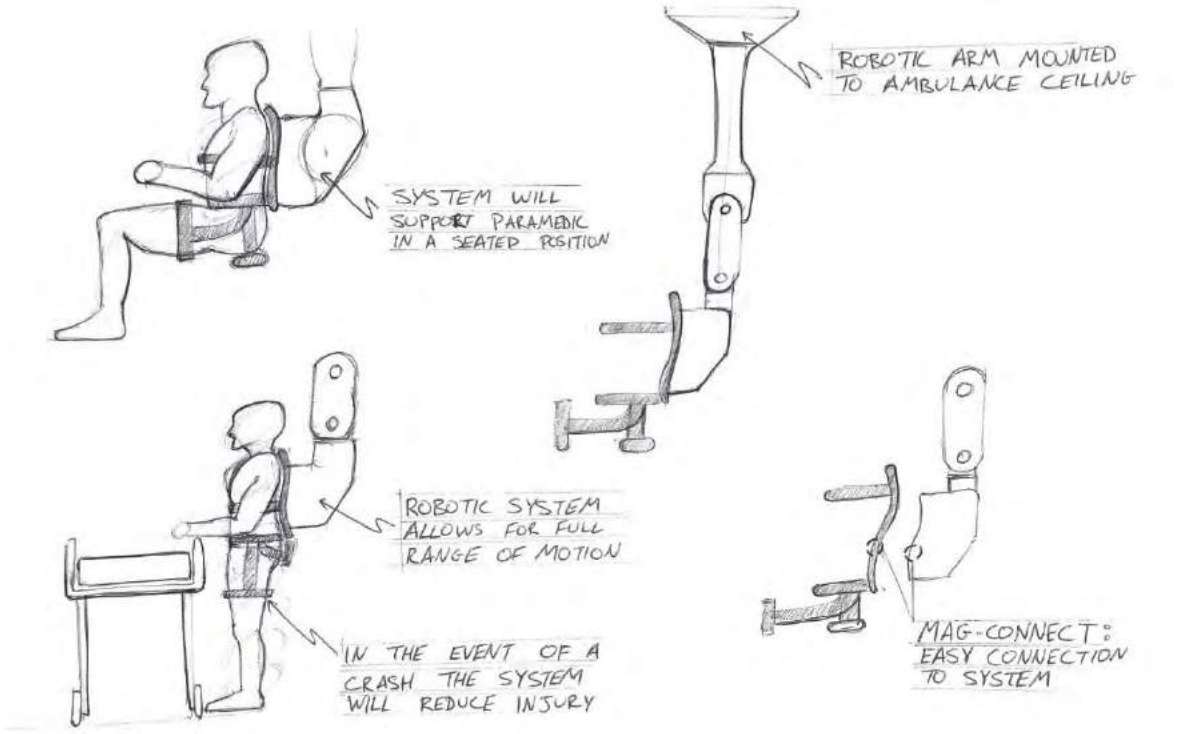


Figure 61 - Ambulance Mounted Paramedic Harness System

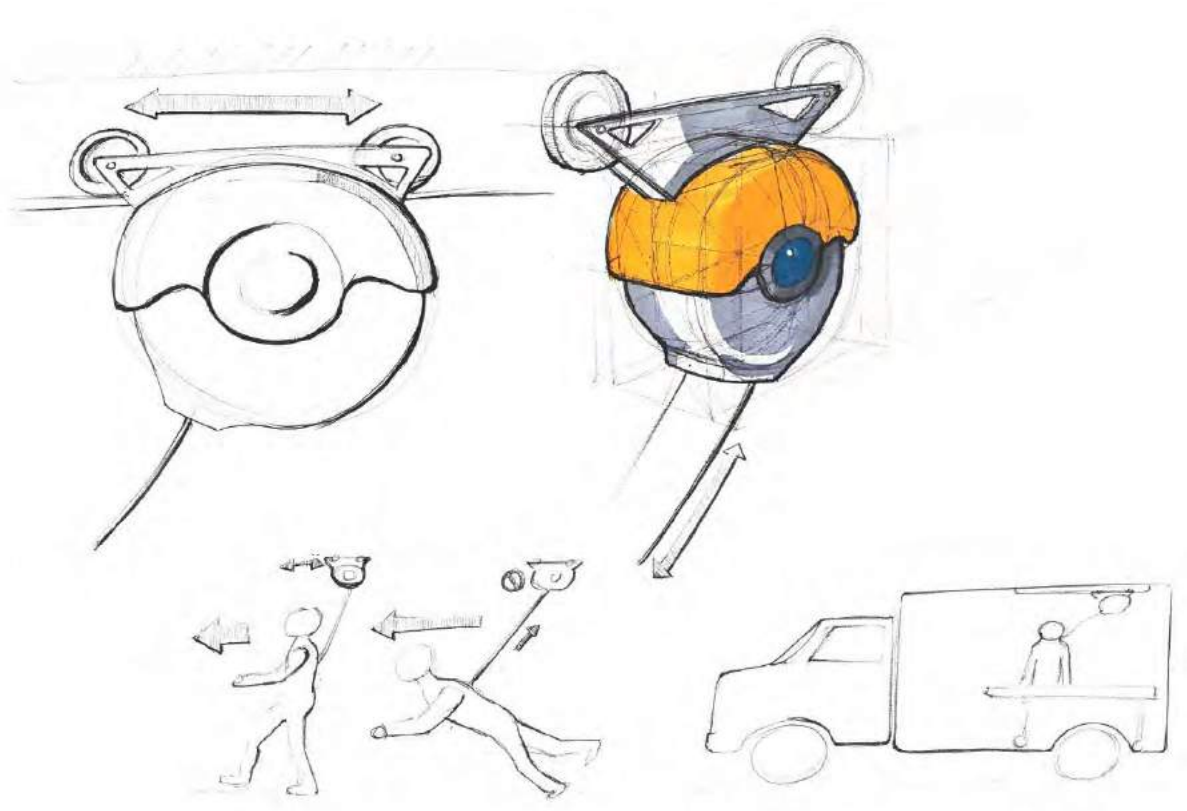


Figure 62 - Retractions System for Paramedic Harness System

4.3 Concept Strategy

While several solutions were explored to help paramedics become more efficient. Two design directions were developed. Concept Direction One being the more dominant of the two directions. Concept Direction One explores the relationship between paramedics and hospitals and attempts to lessen the growing issue of offload delay or the time it takes paramedics to transfer a patient into the hospitals care (Pasma, 2020). Concept Direction Two explores how to better protect paramedics from injury while helping a patient in a moving vehicle. Concept Direction One ended up being chosen as the final design direction.

4.3.1 Concept Direction and Product Schematic One

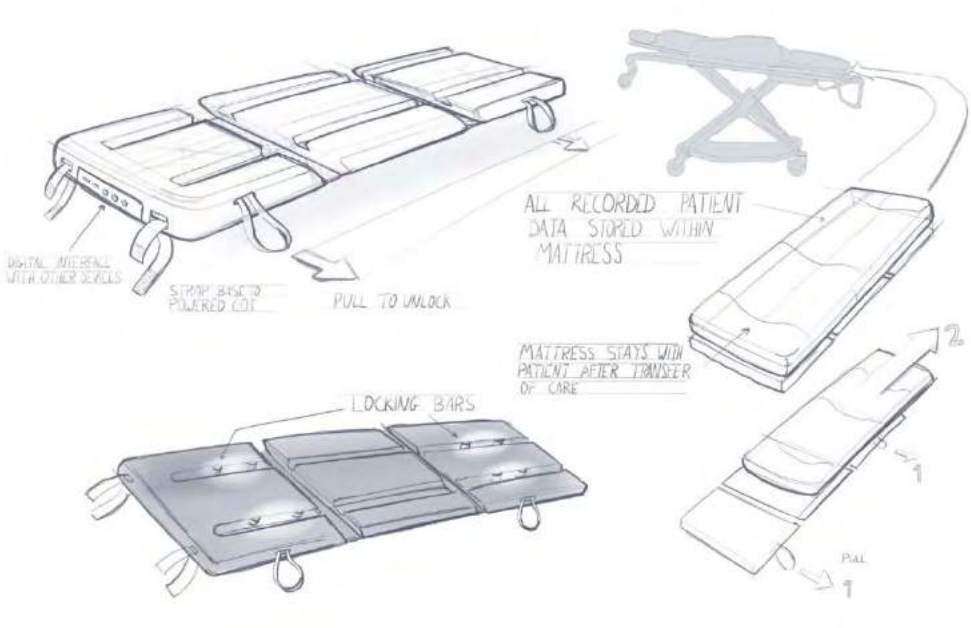


Figure 63 - Docking Station and Smart Mattress

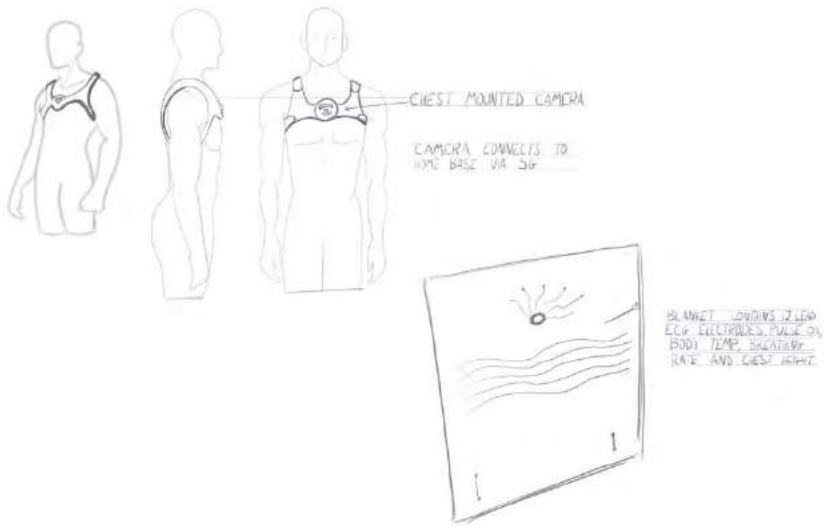


Figure 64 - Chest Mounted Camera and Smart Blanket

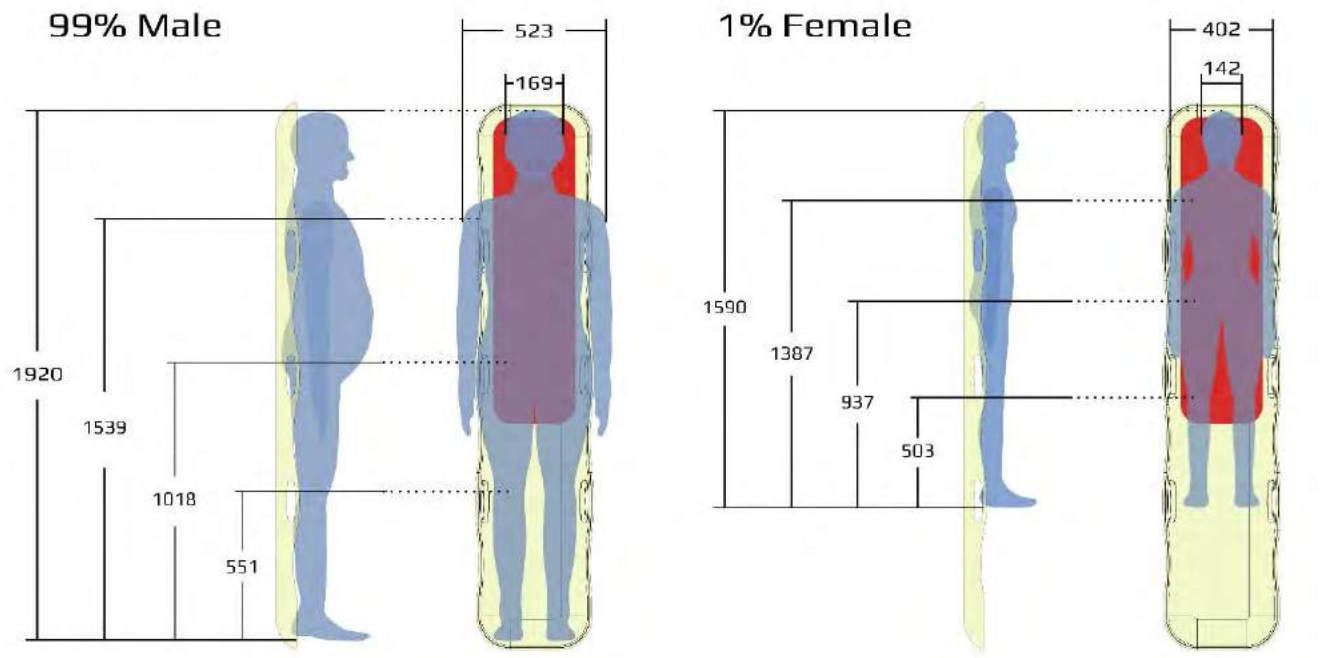


Figure 65 - Initial Anthropometric Diagram of Mattress (Product Schematic)

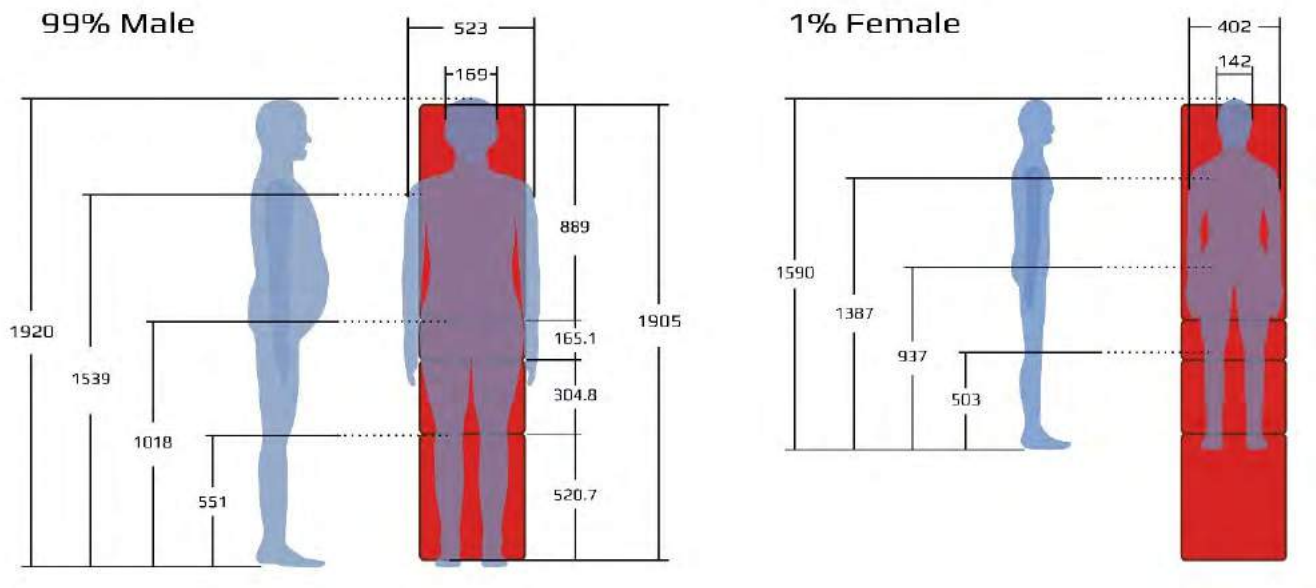


Figure 66 - Initial Anthropometric Diagram of Docking Station (Product Schematic)

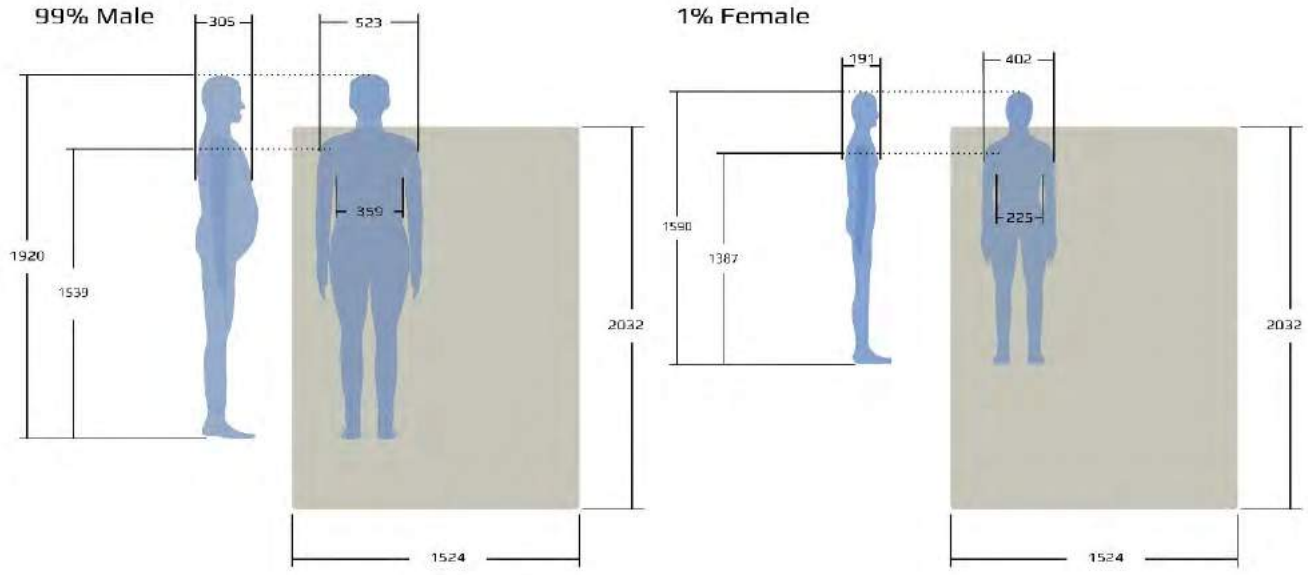


Figure 67 - Initial Anthropometric Diagram of Smart Blanket (Product Schematic)

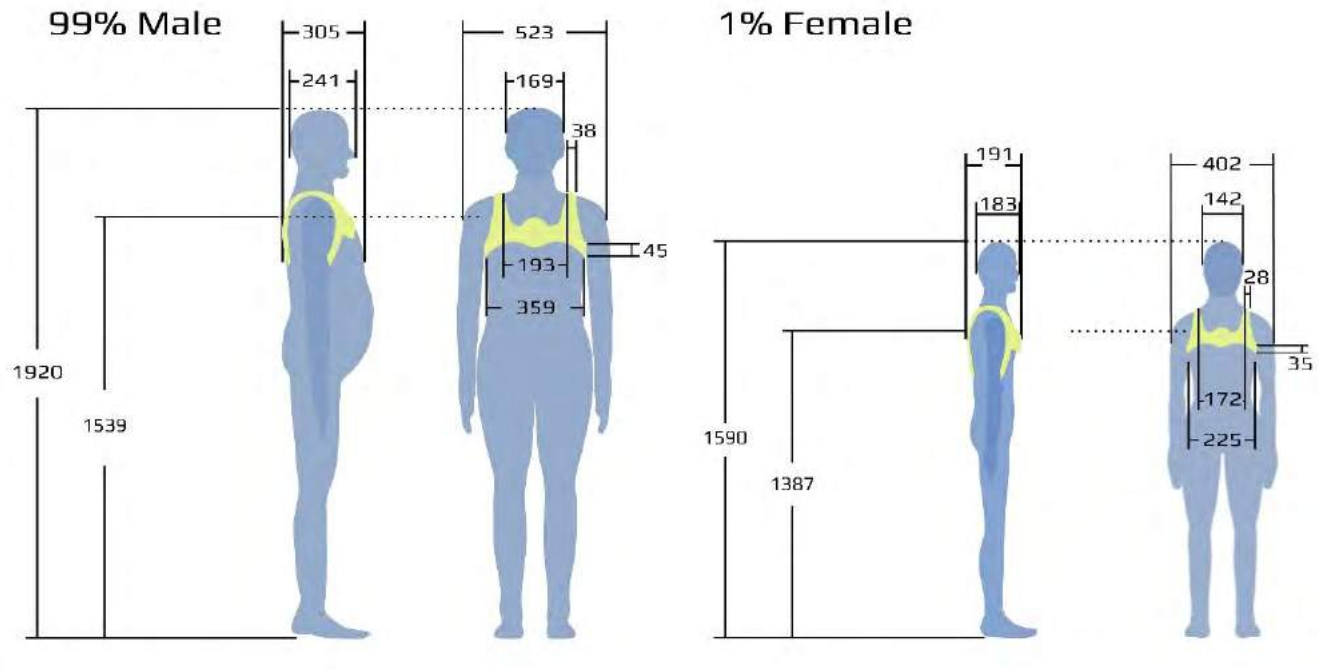


Figure 68 - Initial Anthropometric Diagram of Recording Vest (Product Schematic)

4.3.2 Concept Direction and Product Schematic Two

Due to a lack of time, a product schematic was not created for Concept Direction Two.

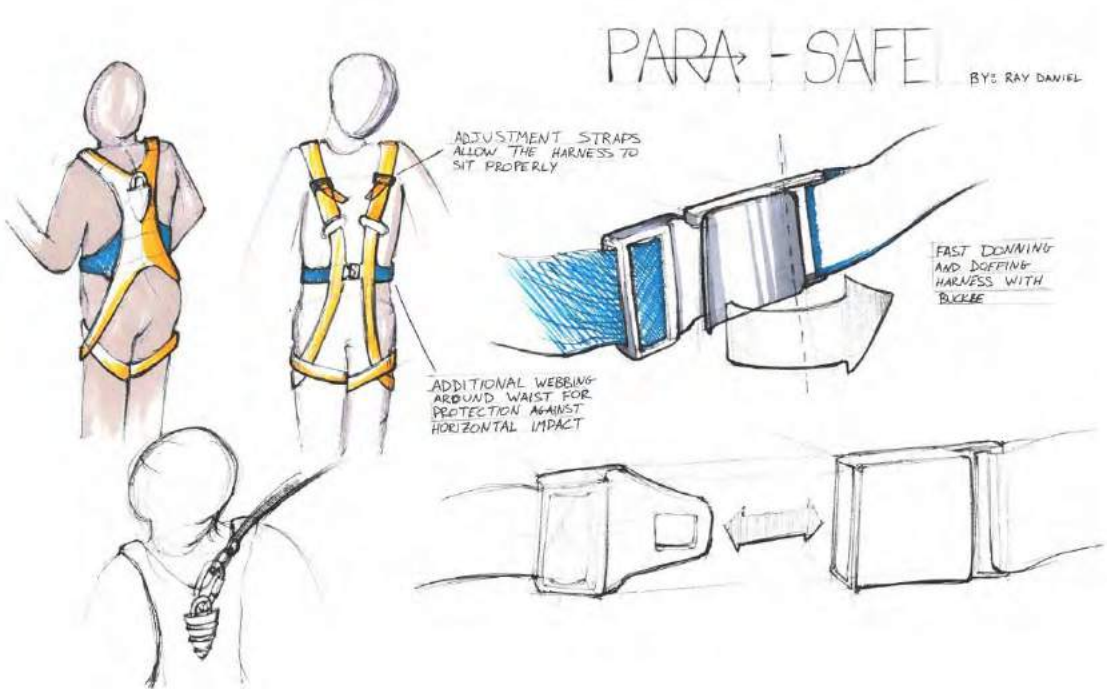


Figure 69 - Paramedic Harness Design

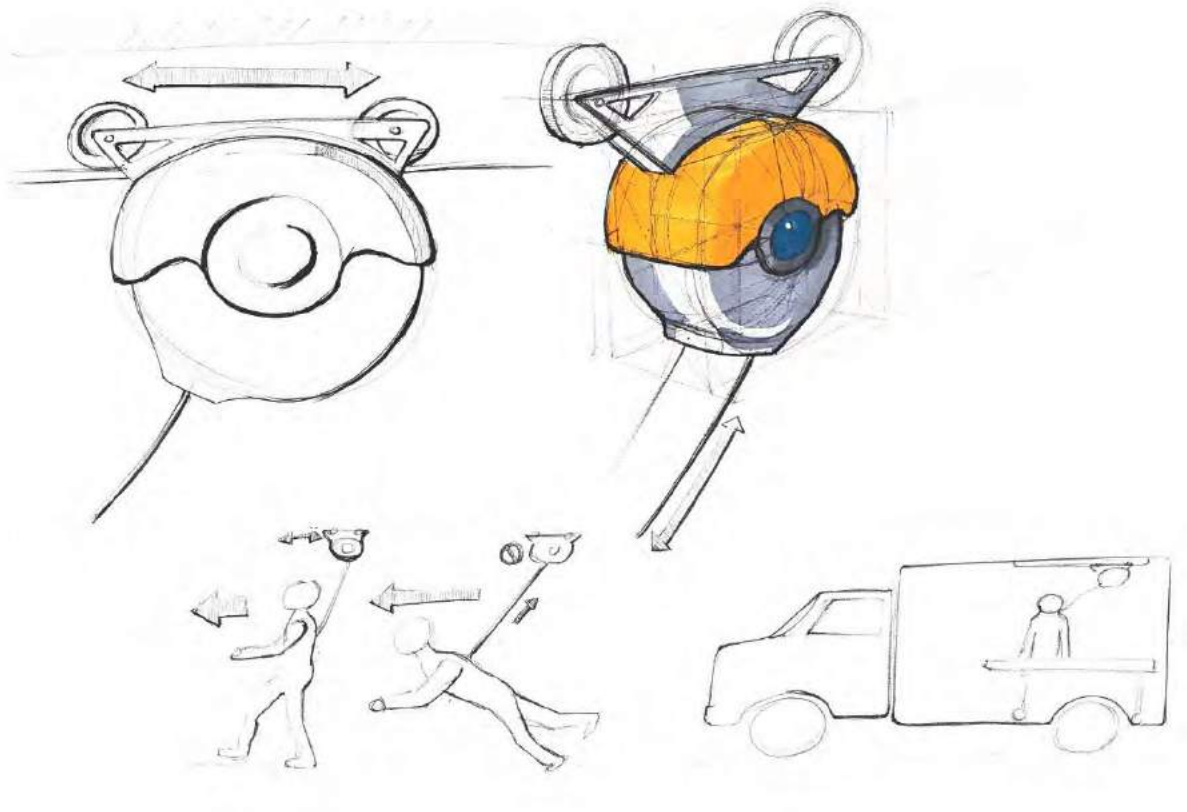


Figure 70 - Harness Retention System Inside Patient Compartment of Ambulance

4.4 Concept Refinement and Validation

As stated above, Concept Direction One was chosen as the design direction of the project. This is partially due to the timely relevance of the patient offload delay. Additionally, the system allowed for more styling opportunity and interaction design development.

4.4.1 Design Refinement

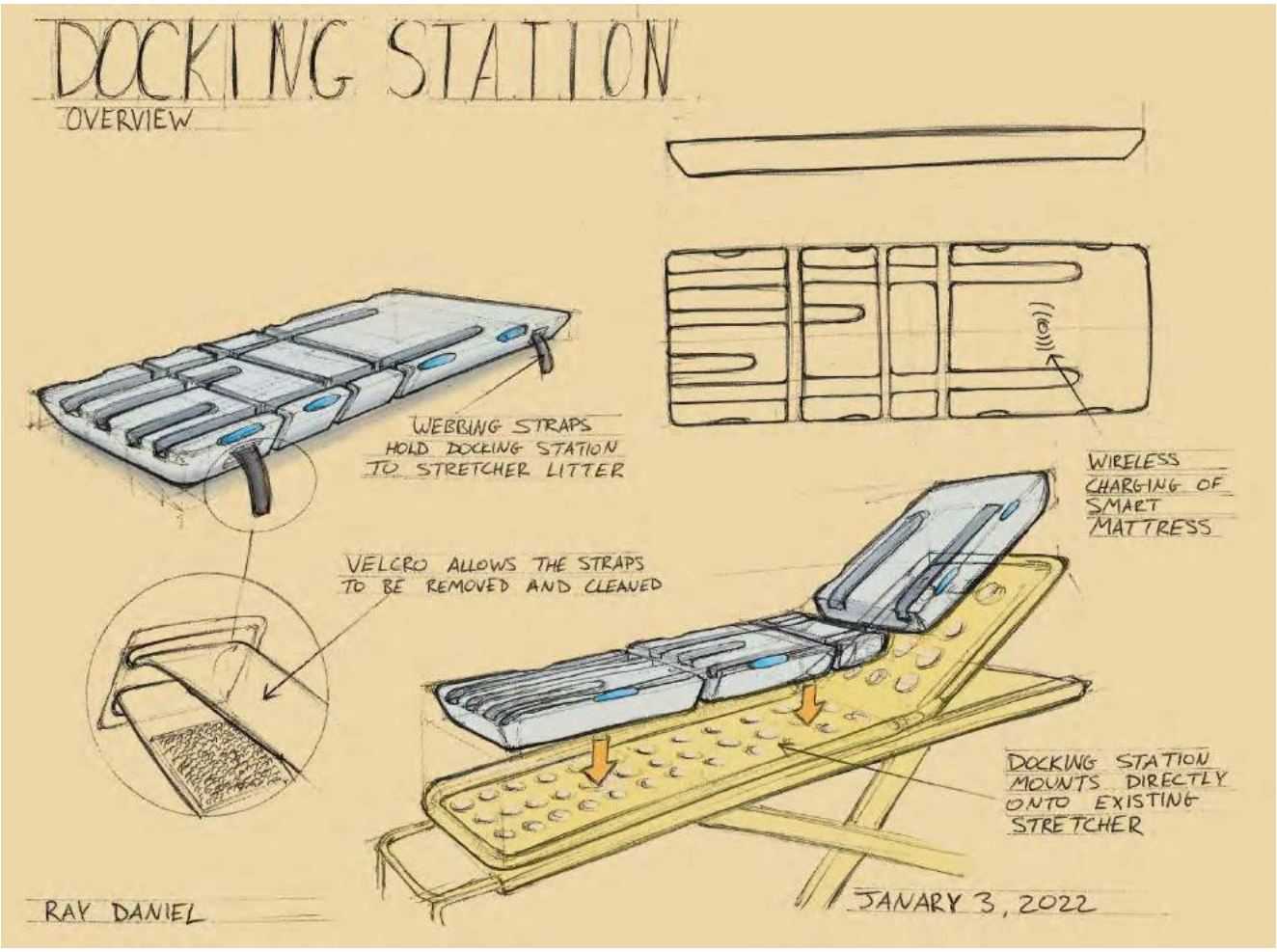


Figure 71 - Docking Station Can Mount Directly Onto Existing Stretcher

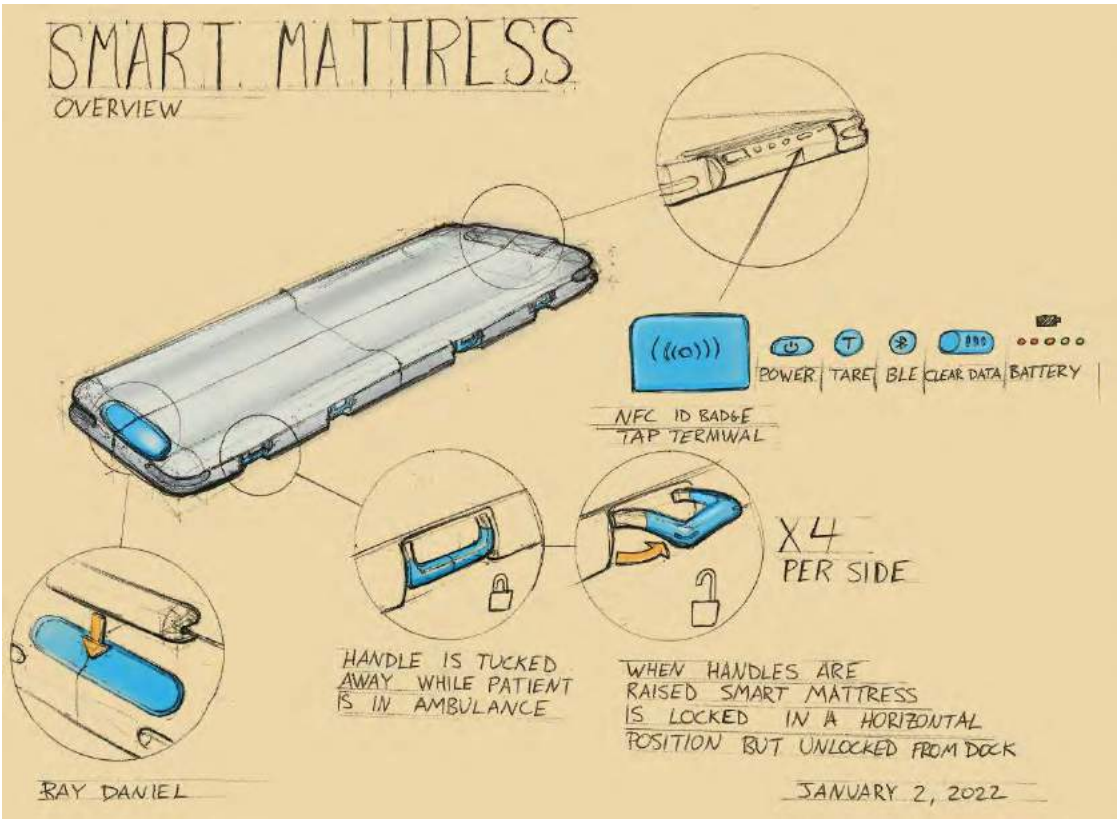


Figure 72 - Smart Mattress Detaches from the Docking Station and Stays with Patient

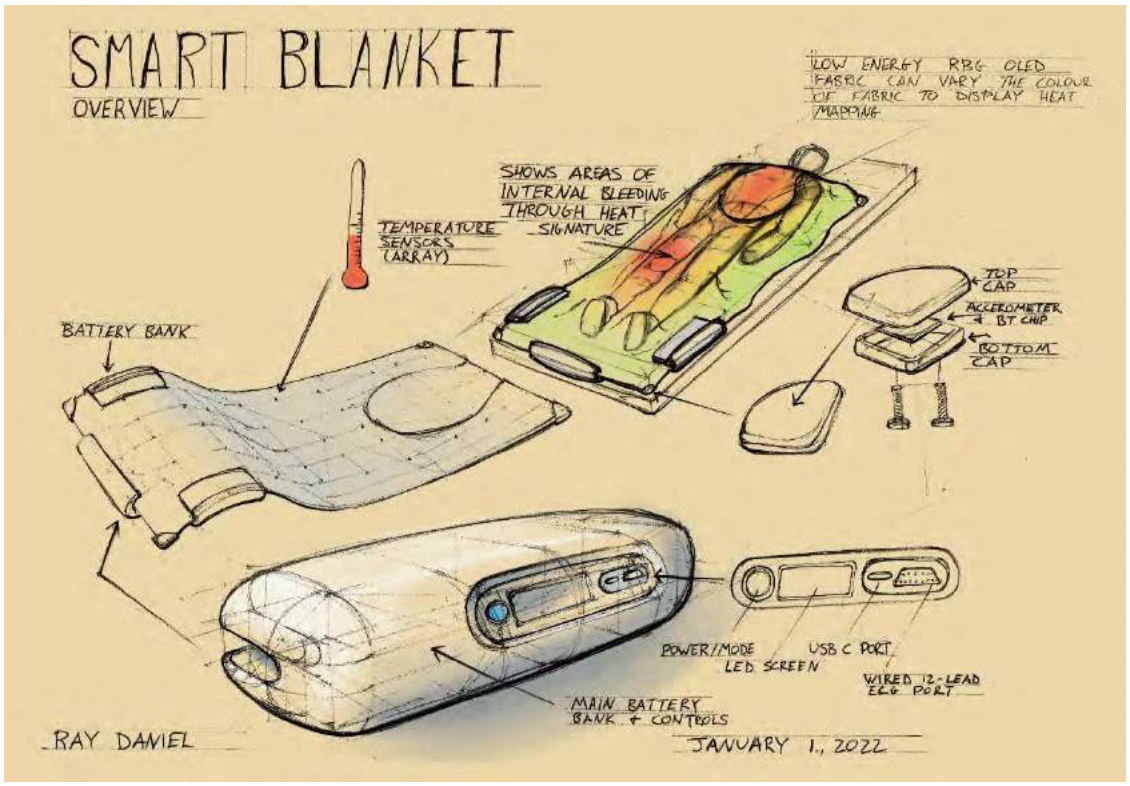


Figure 73 - Smart Blanket is Allows Paramedics to Quickly Determine Major Trauma

4.4.2 Design Development

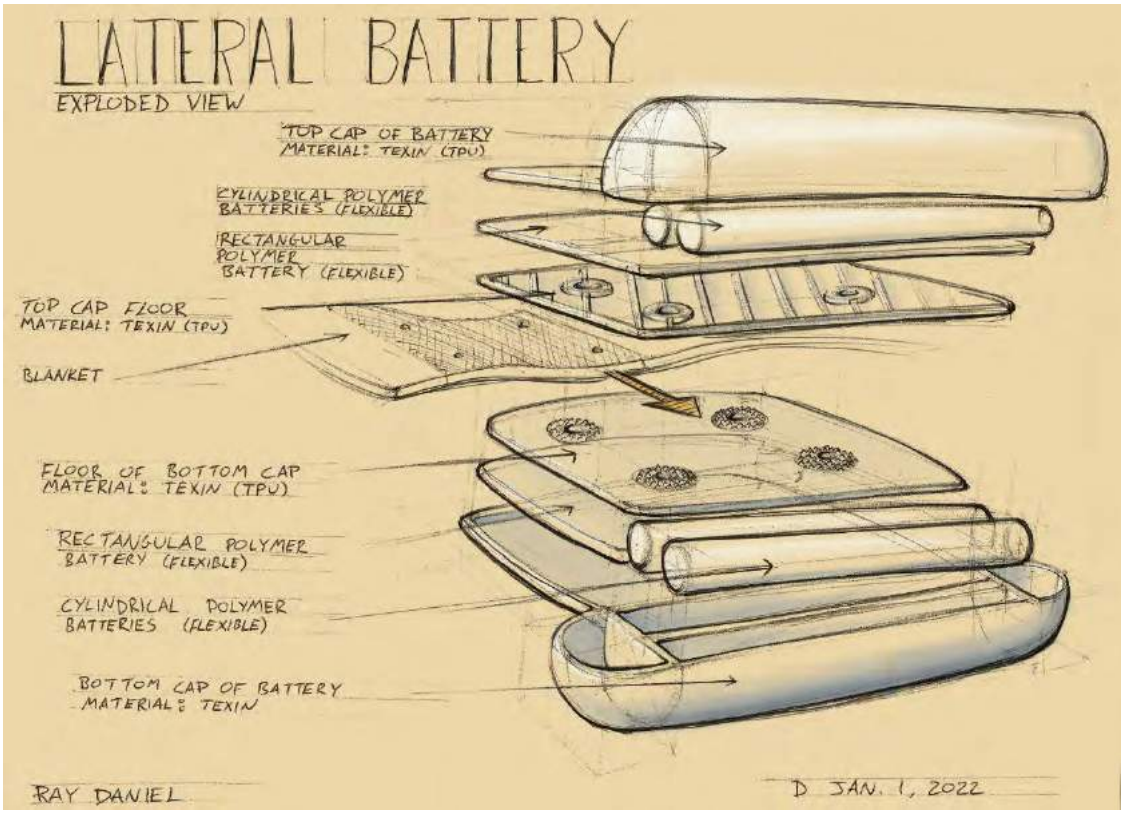


Figure 74 - The Lateral Battery is Attached to the Side of the Smart Blanket

4.4.3 Refined Product Schematic and Key Ergonomic

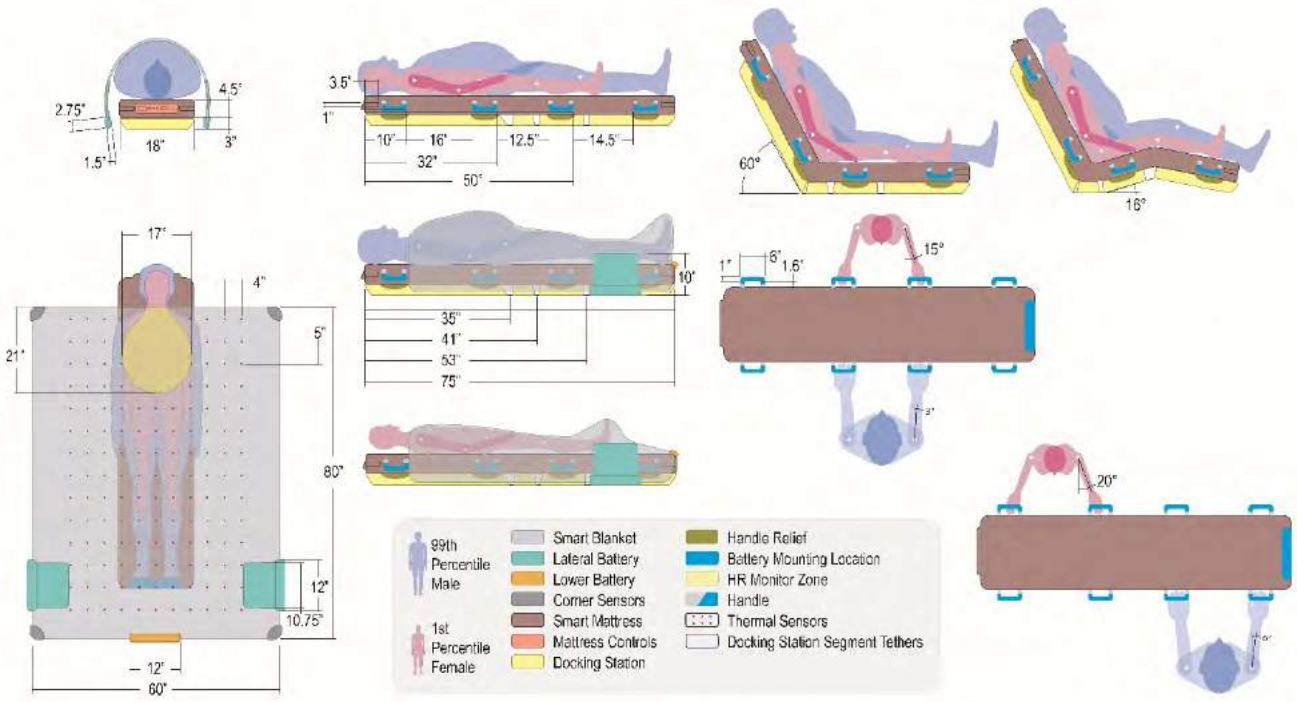


Figure 75 - Updated Product Schematic and Anthropometric Diagram

4.5 Concept Realization

After reviews from both peers within the Industrial Design program as well as the professors and product advisor, a concept direction was finalized. This design of this final concept direct was resolved through the creation of a sketch model.

4.5.1 Design Finalization

The final concept took the design a step further, past the simple rectangular shape of previous iterations. The design maintained its horizontal, calming shape and professional aesthetic while integrating more organic curves to the design. This is due in part to the addition of a blue whale as reference inspiration. The majestic blue whale swims peaceful in the blue waters of the ocean, its massive, sleek body glades through he waters with confidence. The sight of a blue whale invokes feelings of wonder, tranquility, and awe; see Figure 76.

Figure 76 - A blue whale swimming (Fiona, 2019)

With the addition of the organic curvature, the ZEROCODE system is much more approachable both by the paramedic and the patient. Figure 77 displays some of the initial explorations of this new curved design

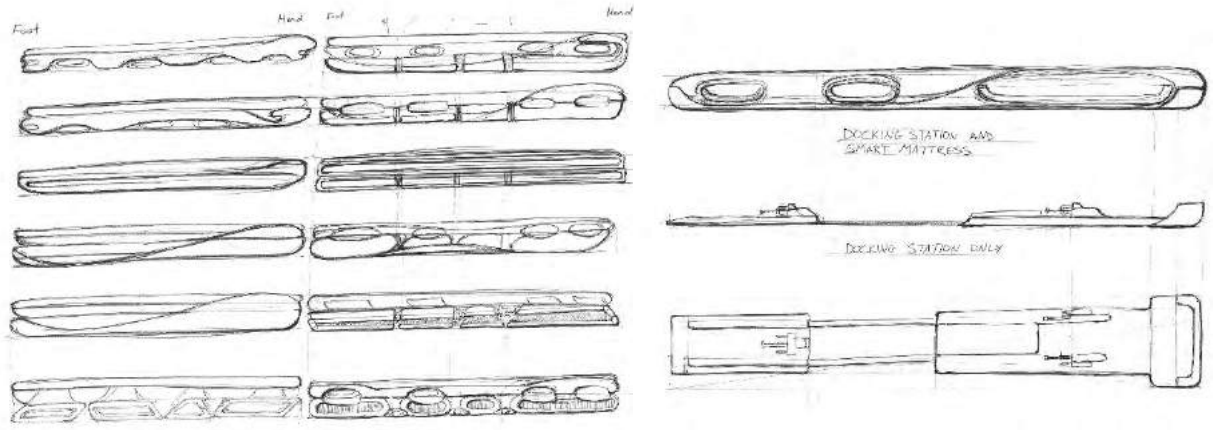


Figure 77 – Left: Exploration of more curves on side profiles; Right: Design direction

Once a design direction of was chosen for the side profile, its shape and colour interaction was explored. Figure 78 shows a further resolved version of the ZEROCODE system compared to the design seen in Figure 77. Figure 78 shows the exploration of foreground and background as the off-white outer mattress interacts with the dramatic blue inner mattress.

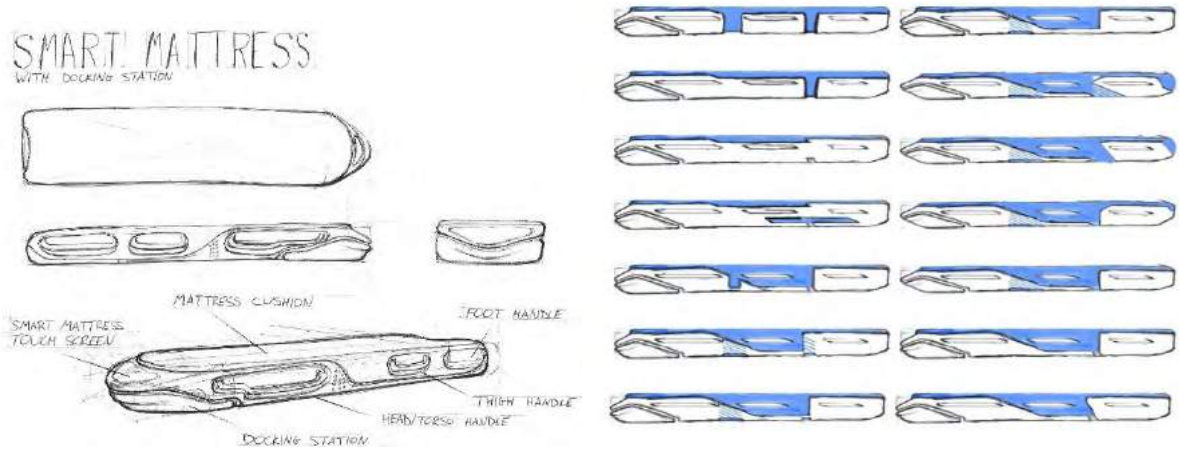


Figure 78 - Further exploration of the interaction of inner and outer mattress

During the exploration of the system's side profile, the question of whether the Docking Station needs to be as thick as previously draw was asked. The initial question was answered with another question: "What does the Docking Station do/house"?

Diving deeper into the second question suggested that the Docking Stations provided three functions:

1. Guide and lock the Smart Mattress onto an existing stretcher frame
2. Power/Charge the Smart Mattress
3. Remain, substle and out of the way whenever possible

With a clearer idea of what the Docking Station needs to be, a slimmer, lower profile version of the Docking Station was developed. This new version employed a larger head to stop and lock the Smart Mattress onto the stretcher frame. However, the rest of the Docking Station was tucked neatly under the Smart Mattress while the system was on the stretcher frame. This sleeker design can be seen in Figure 79.

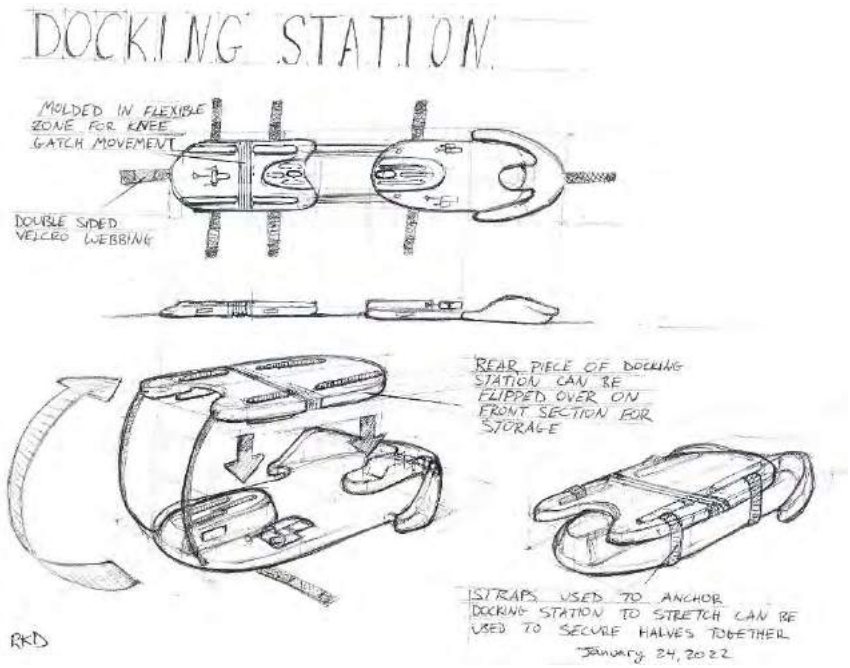


Figure 79 - Refined design of a lower profile Docking Station

Once the design direction had been further resolved, the ergonomics of the mattress and configuration diagram were revisited; See Figure 60. Some notable changes include a reduction of handles per side, 3 down from 4, the removal of the side mounted batteries on the Smart Blanket and removal of the corner sensors. Additionally, the shape and size of the ECG area was further resolved for a cleaner appearance.

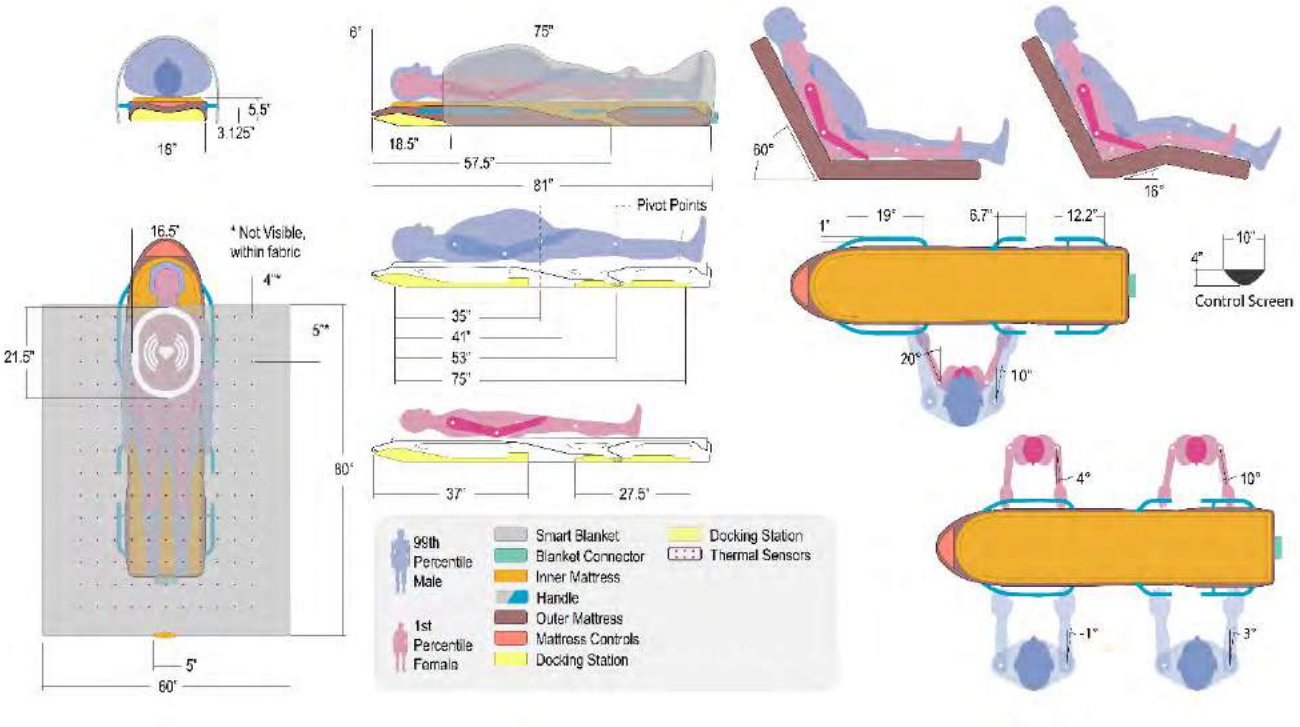


Figure 80 - Finalized Configuration Diagram

1.5.2 Physical Study Models

The physical model study allowed for the exploration and understanding of the interaction between the three parts of the system. Various materials were used to make an inexpensive physical model.

Figure 81 - Smart Mattress Sketch Model

The Smart Mattress sketch model was constructed mainly out of pink foam. This allowed me to quickly sculpt the body and explore the shape and size of the rails underneath. The Mattress was constructed out of white chair cushion foam. It was dyed blue using India ink to properly perceive the contrasting blue and white side profile. From this model, I learned that the rail shapes on the bottom cannot extend all the way to the front but rather stop at the inner wall of the Docking Station; see Figure 62 for details.

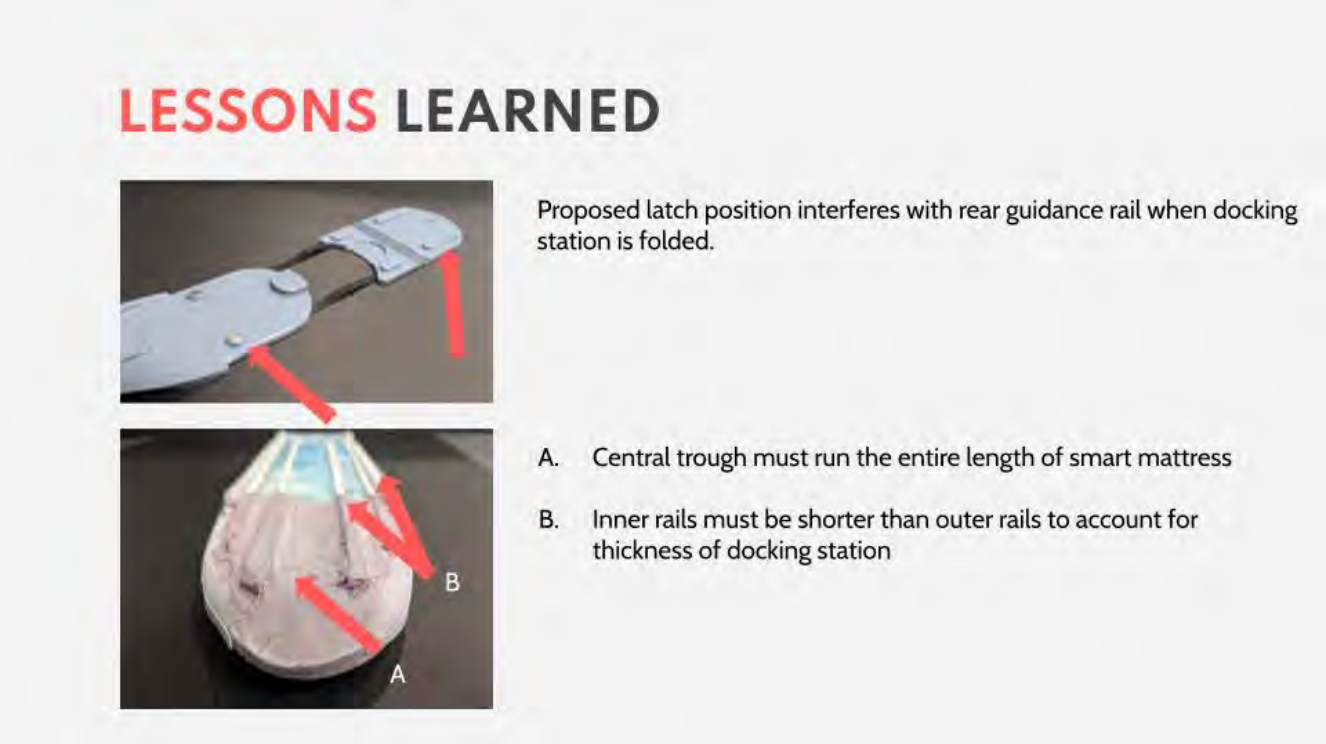


Figure 82 - Lessons learned about the Smart Mattress

The Smart Blanket Sketch model was made from the same fabric as the final model. This was done to learn the characteristics of the fabric. Due to the highly conceptual nature of the blanket, many of the features could not be shown in the sketch model or the final model. Therefore, it was imperative that the Smart Blanket model be convincing enough through appearance alone. See Figure 83 for a view of the Smart Blanket.

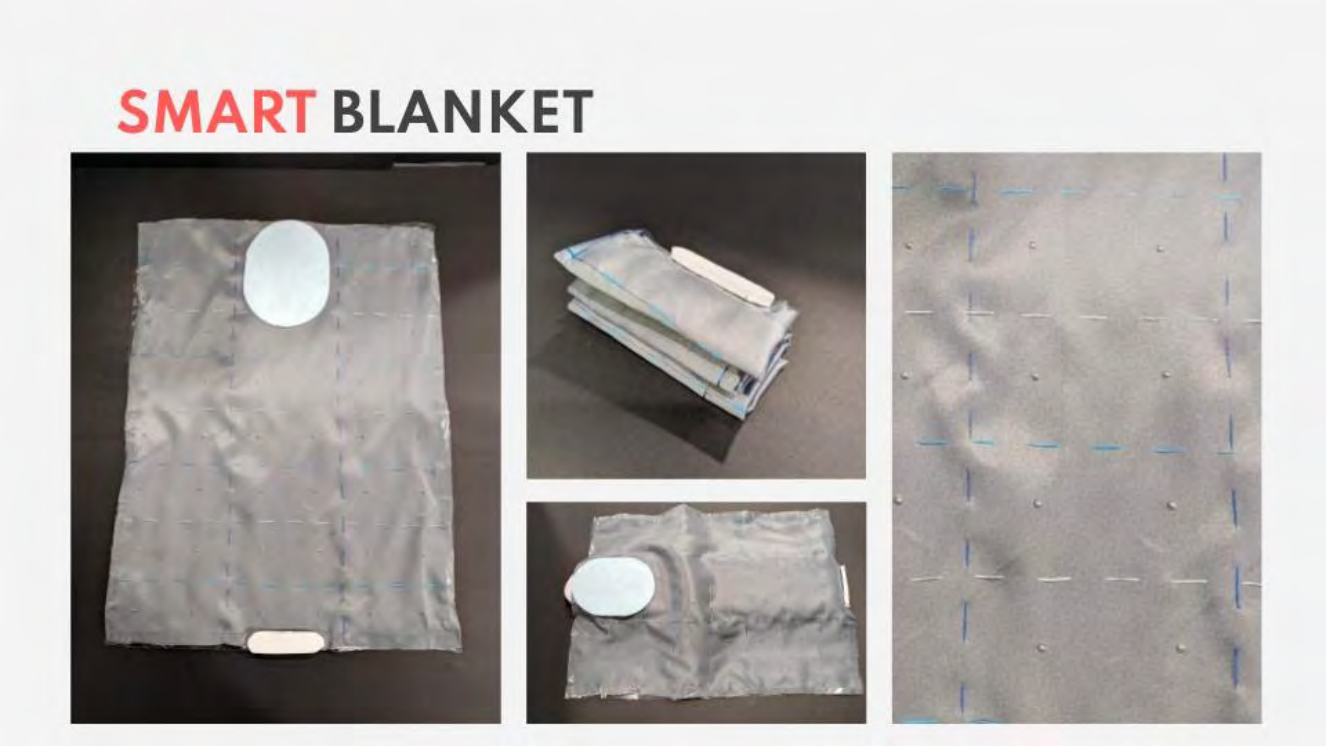


Figure 83 - Smart Blanket design

Finally, the Docking Station was 3D printed on a Filament Deposition Manufacturing (FDM) printer. Since the final design was intended to be grey, a grey filament was chosen rather than painting an alternative colour.

Figure 84 - Docking Station

4.6 Design Resolution

After the complete of the physical sketch model, there were only minor tweaks to the design. However, the model would consist of a mattress that has a white textured outer shell (the Outer Mattress) which appears to wrap around and cradle a high gloss, air filled, transparent blue TPU inner mattress, Figure 65. A Smart Blanket with wireless vitals measurement (breathing rate, heart rate, blood-oxygen levels, and temperature), see Figure 66, Figure 67, and Figure 68. Finally, a satin grey TPU docking station, See Figure 69.

Figure 85 - Final Design Direction for Smart Mattress

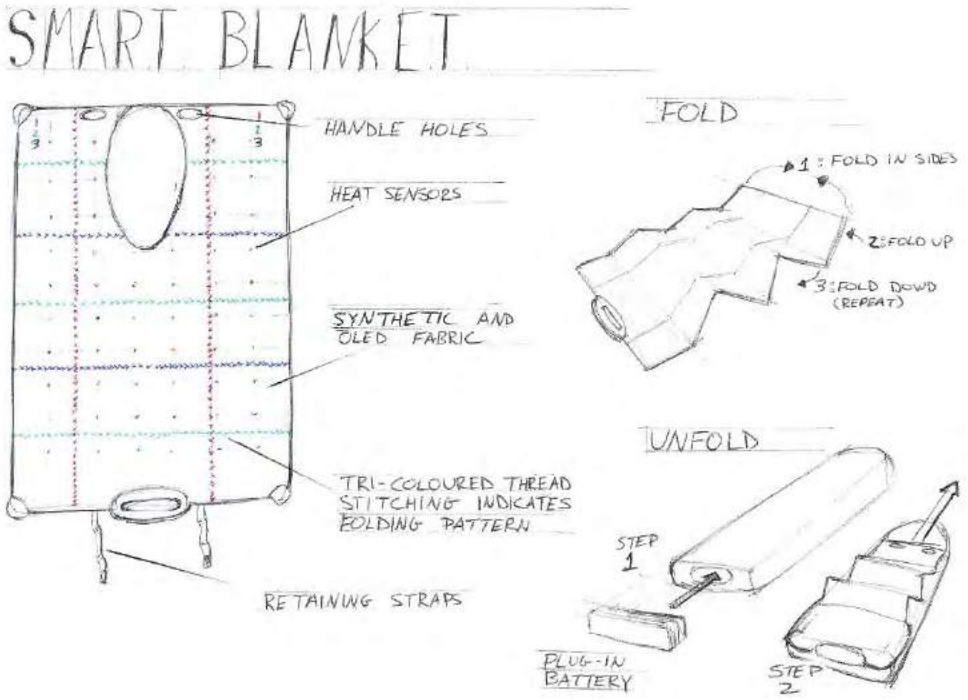


Figure 86 - Smart Blanket

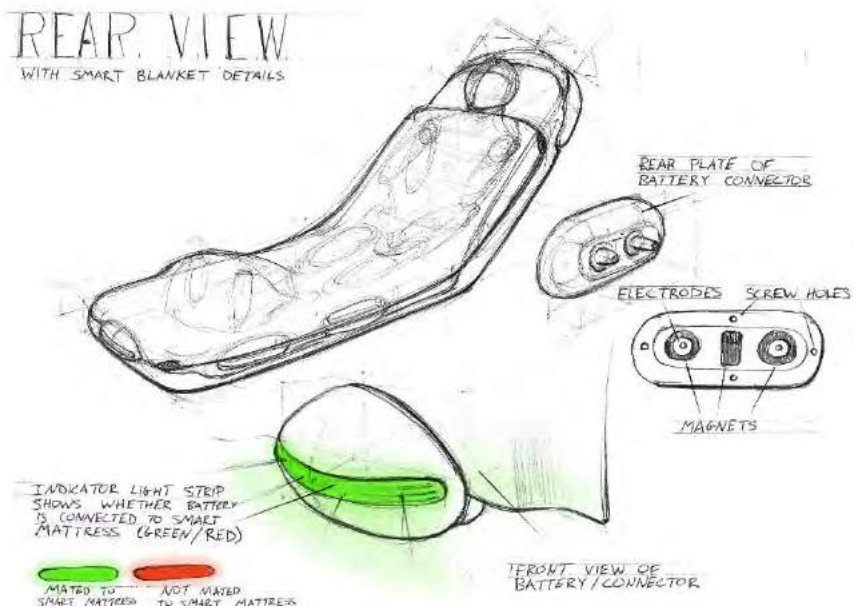


Figure 87 – Smart Mattress and Blanket Together 1

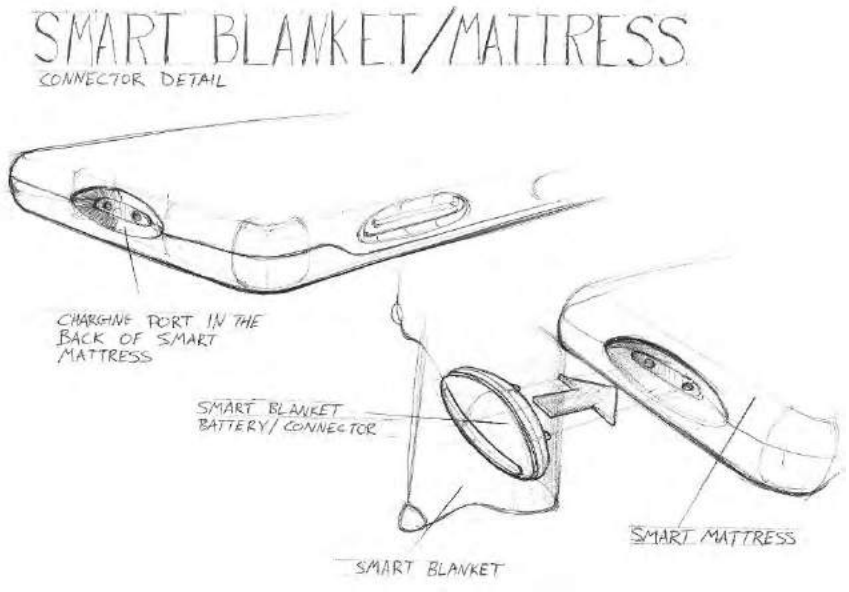


Figure 88 - Smart Mattress and Blanket Together 2

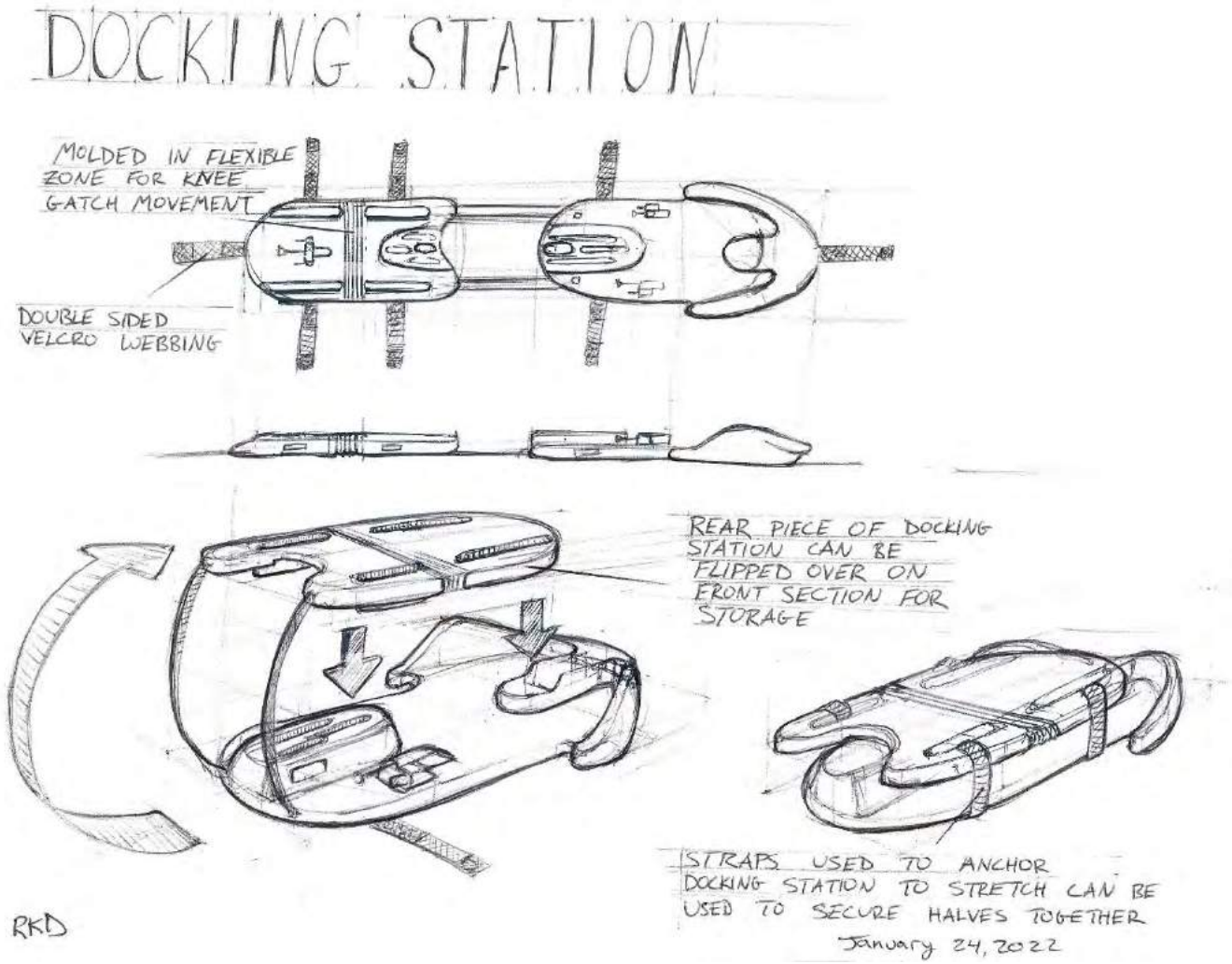
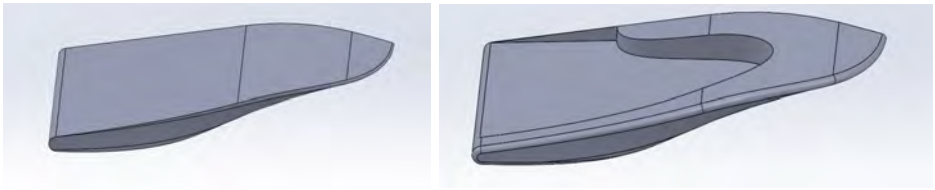
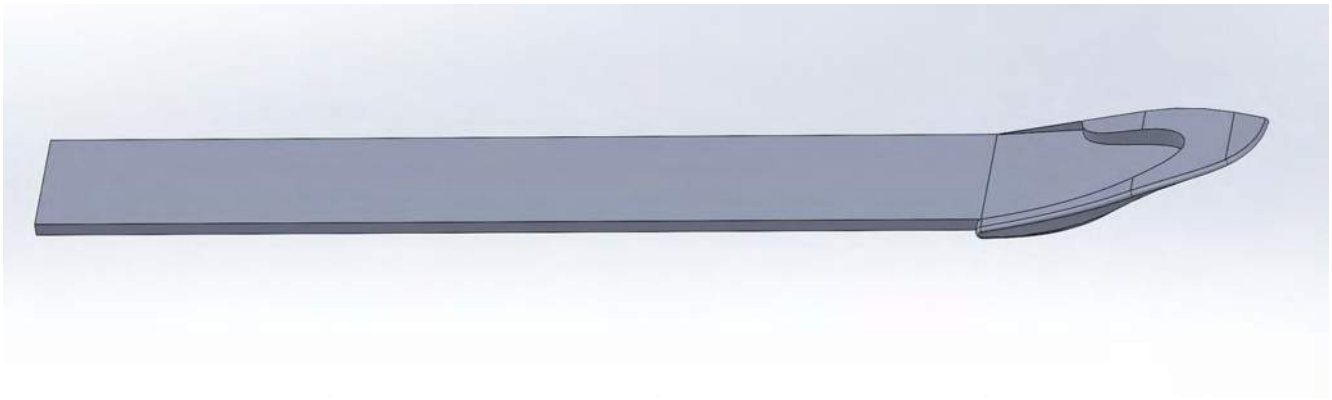


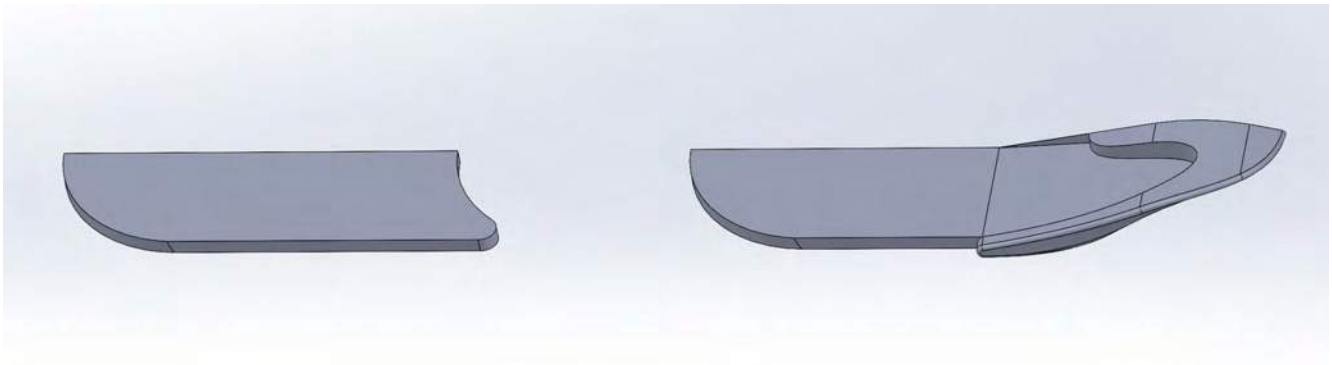
Figure 89 - Docking Station

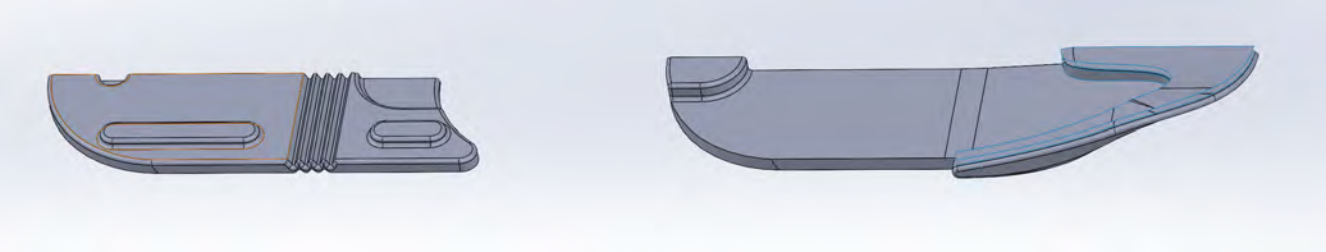
4.7 CAD Development

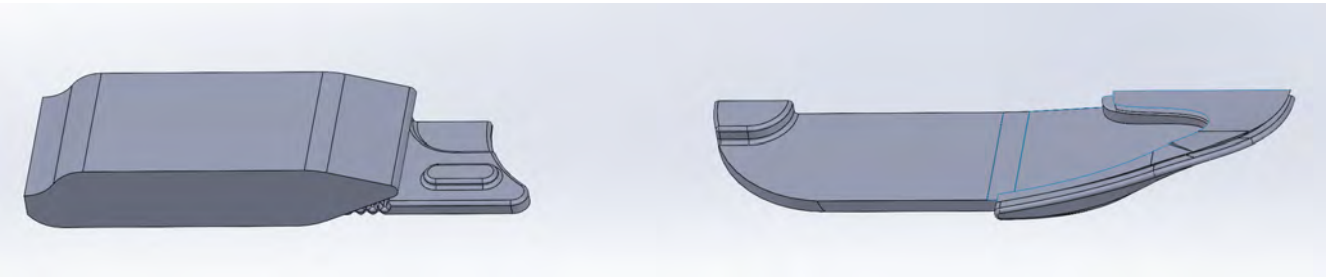
The CAD development happened over an 8-week period, with the majority of the CAD completed withing the first 5 weeks. Solidworks was used to construct the model, employing both solid and surface modeling to achieve the result. (CAD images not in figure count). See Appendix E

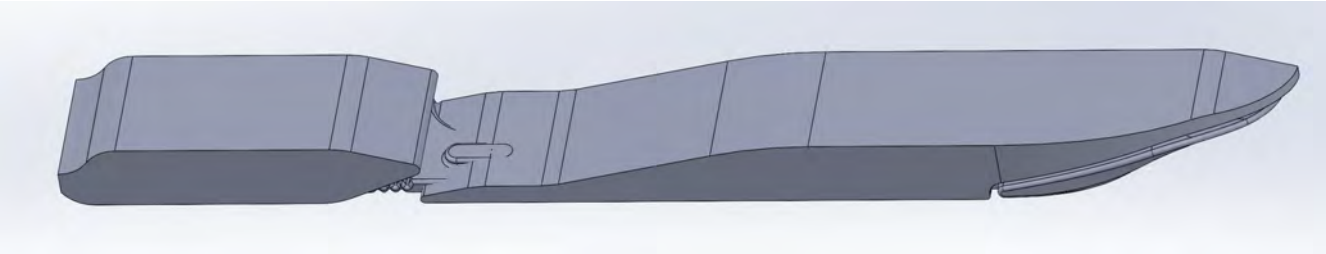


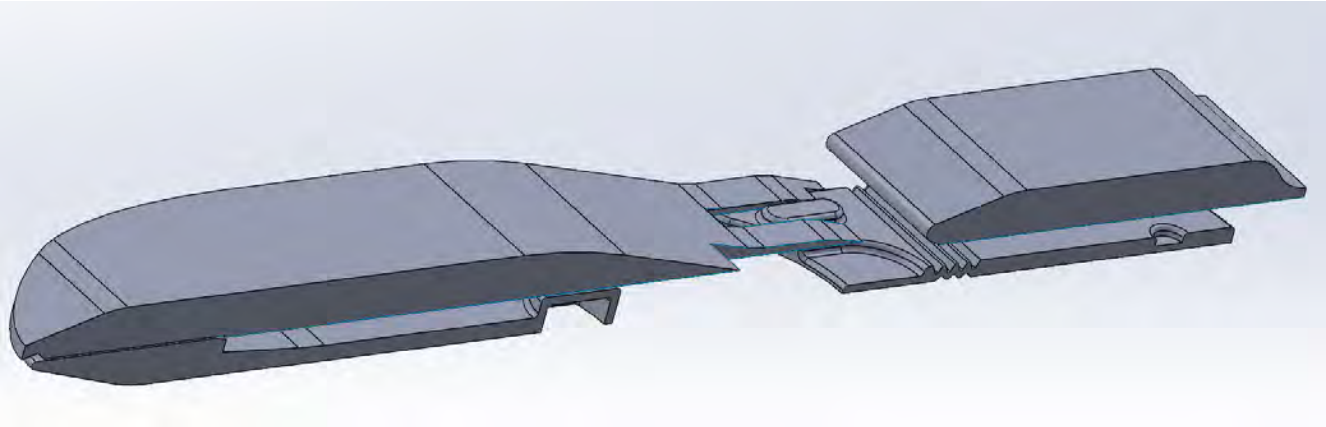


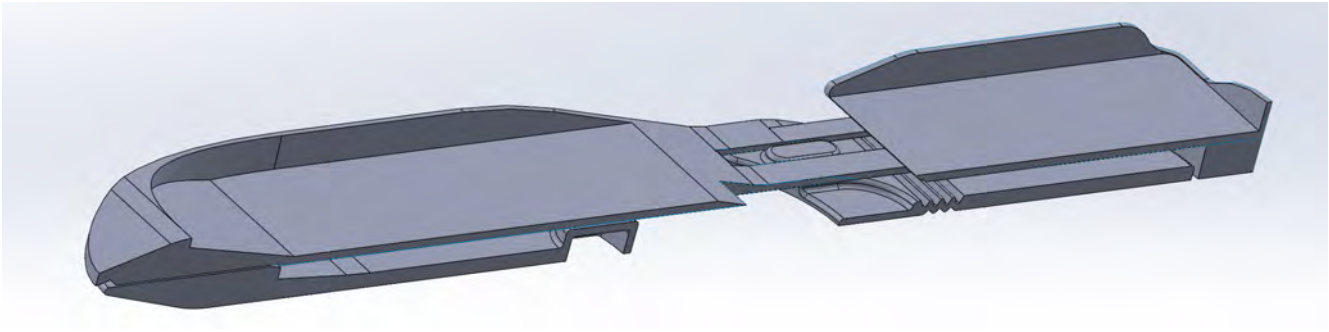


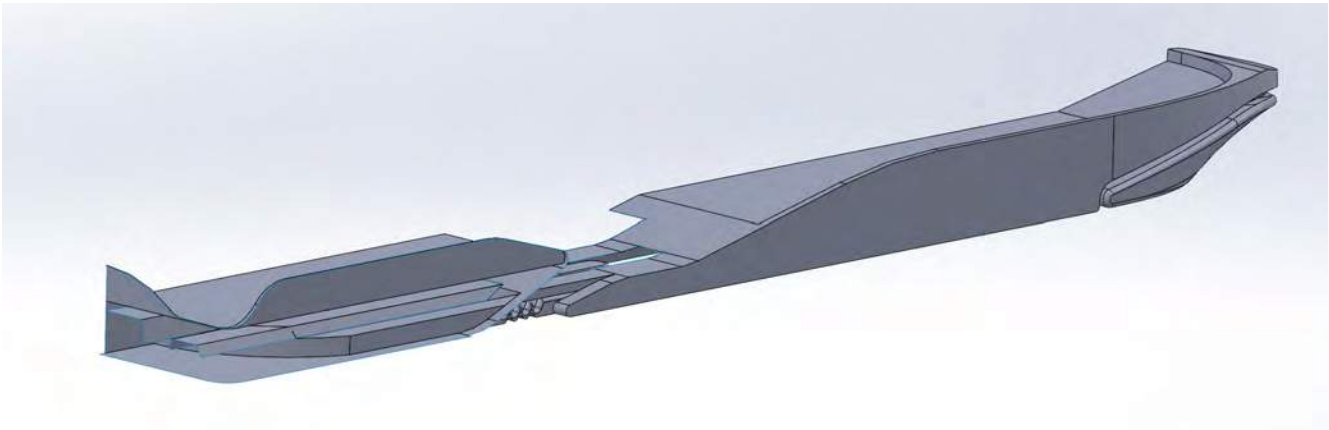


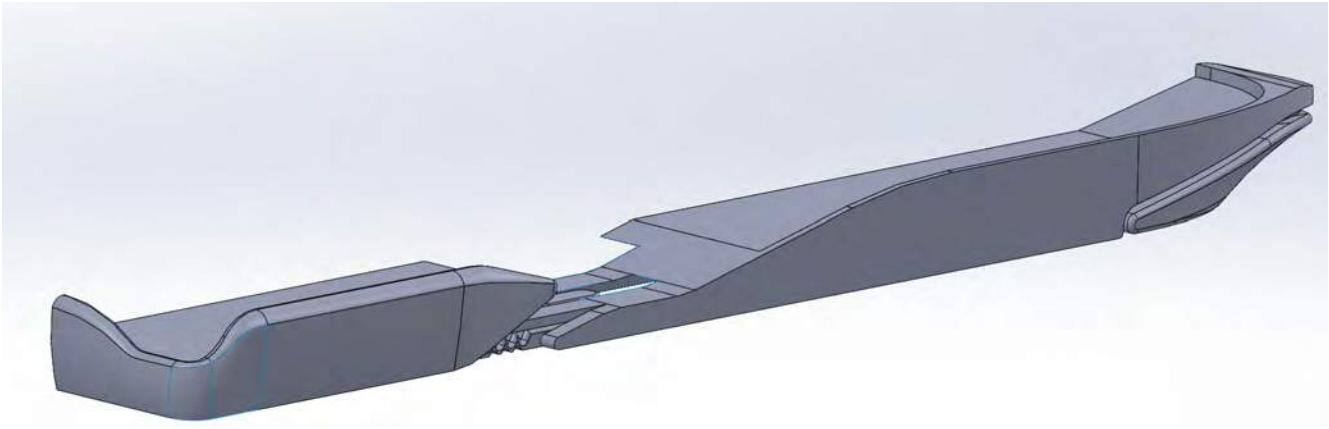


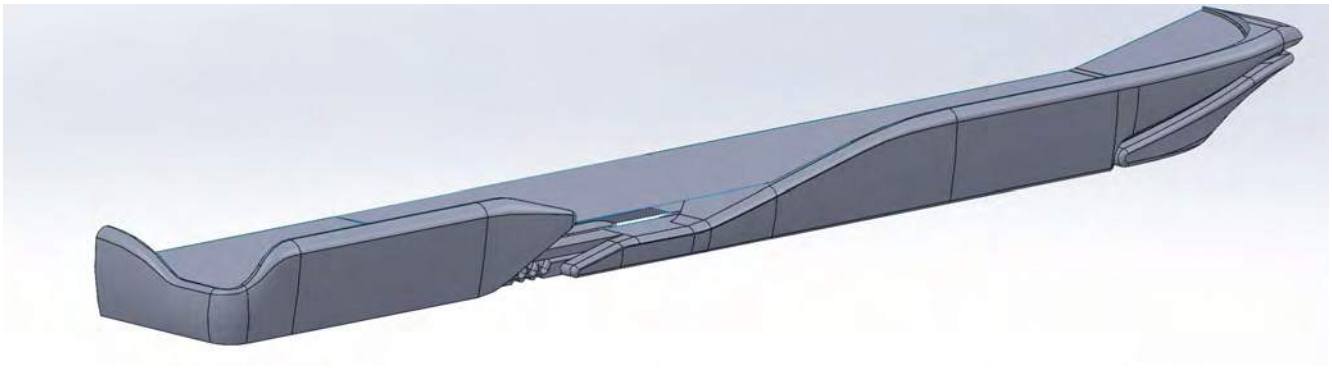


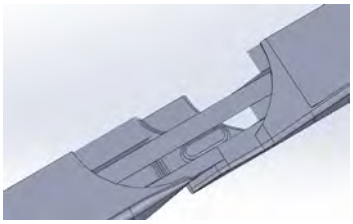


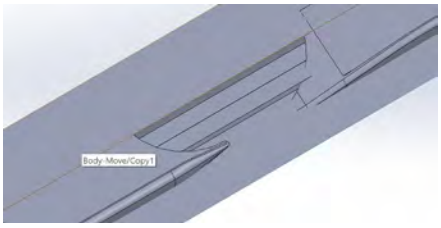


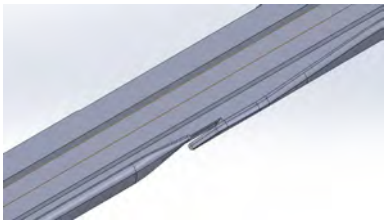


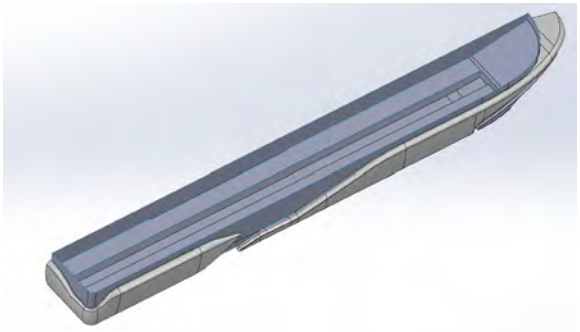


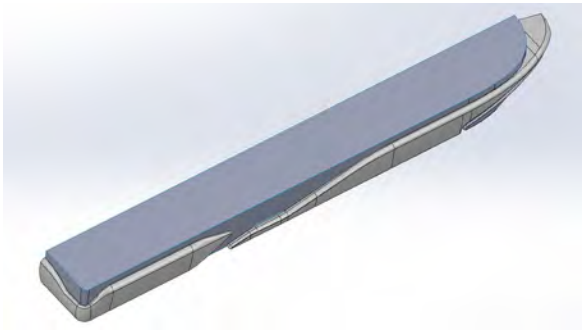


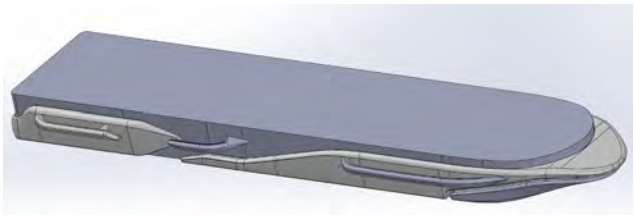


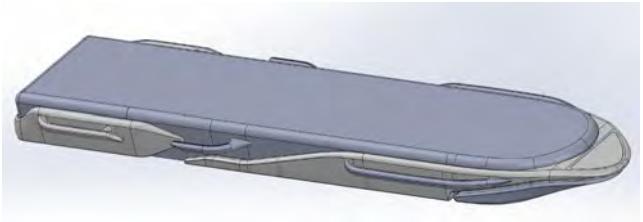

Body-Move/Copy1

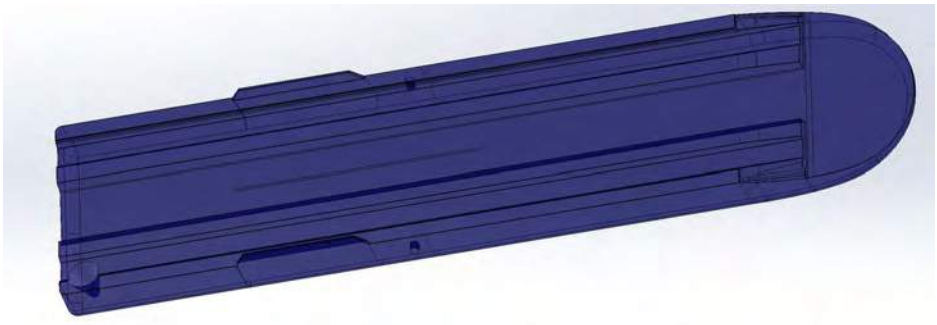


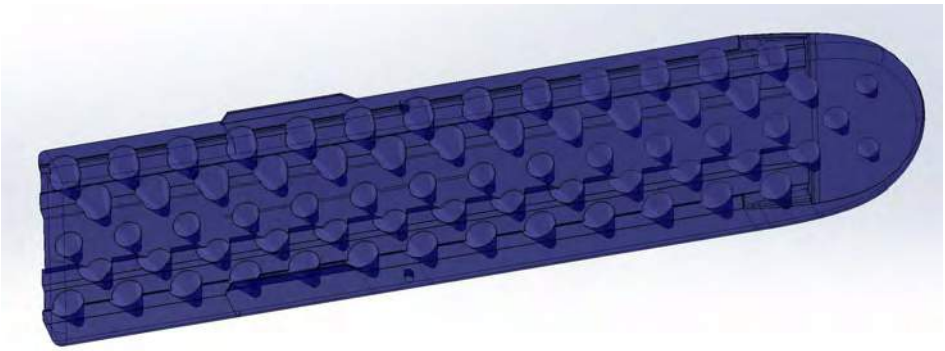


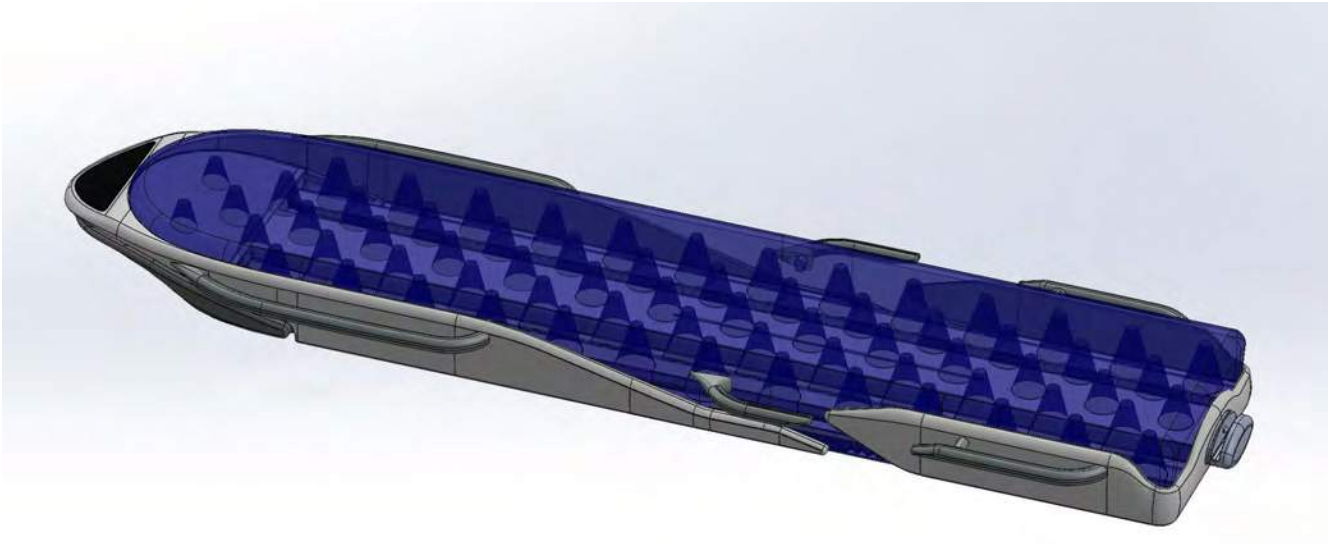












4.8 Physical Model Fabrication

The physical model had a soft portion and a hard portion. The soft portion was created sandwiching thin cotton batting between two pieces of synthetic fabric. The assembly was commissioned to a volunteer to sew together. The stitch pattern was chosen to represent the robust nature of the blanket but also to be clearly visible.

Figure 90 - Machine Sew the Smart Blanket

The hard potion of the physical model was 3D printing at two different locations. The Docking Station and the Outer Mattress were printed at Agile Manufacturing using the Stereolithography (SLA). Do to the unique nature of the of the inner mattress, the 3D printing operation was handled by Objex Unlimited who used the Mimaki CMYK. The printer can print clear resin while impregnating it with CMYK ink. This allows the printer to print semi-transparent objects. The finishing was also completed by Objex Unlimited, see Figure 91.

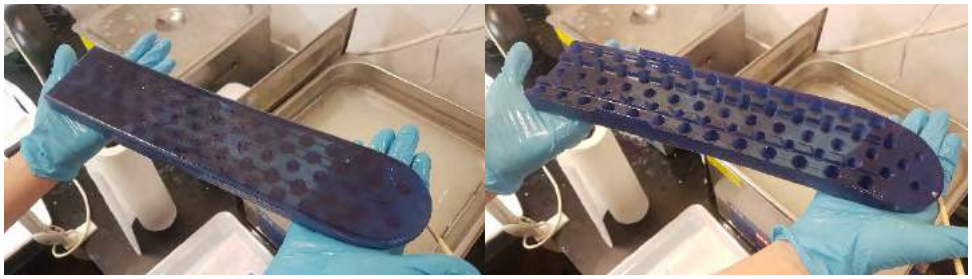


Figure 91 - 3D Printing of Inner Mattress from Objex Unlimited

The Outer Mattress and Docking Station were then wet sanded, primed and spray painted their respective colours, see Figure 92.

Figure 92 - SLA parts were primed and wet sanded, then painted

The handles also followed a similar treatment. See Figure 93.

Figure 93 – Handles

Once everything dried the model was assembled Figure 74.

Figure 94 - Model Assembly

The final model!

Figure 95 - The Final Model

CHAPTER 5 Final Design

5.2.1 Full Bodied Interaction Design

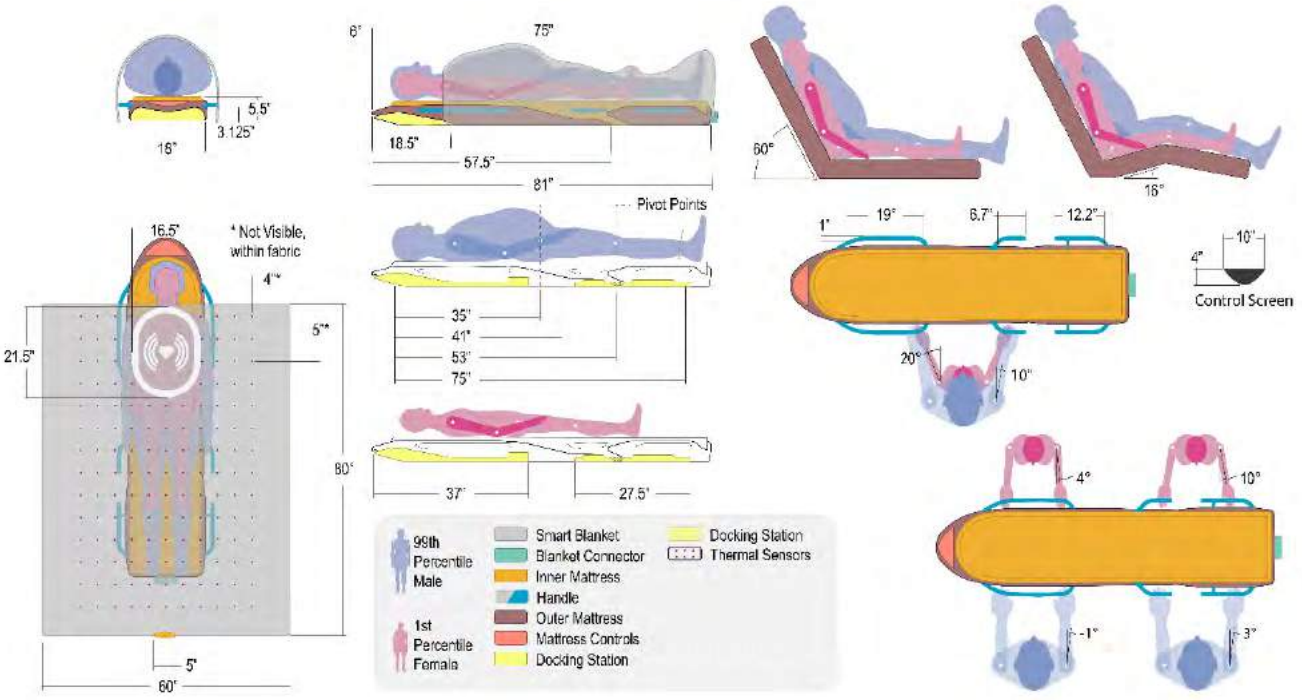


Figure 96 - Final configuration diagram

5.2.2 Materials, Processes and Technology

This section will be broken in the three main sections of the ZEROCODE system: Smart Blanket, Smart Mattress and Docking Station. Each subsection will discuss the various chosen materials of the system's components, the estimated manufacturing processes, and any technologies involved within the systems.

Smart Blanket

Traditionally, many of the materials used in medical textiles are either not reusable or not recyclable. However, there are currently other alternatives; for instance, reusable medical textiles are

presently made of polyester, an umbrella term that includes polyethylene terephthalate (PET) and polylactic acid (PLA) (Sun, 2011). PLA is also considered biodegradable. This reusable PLA fabric can be combined with new luminous fibres in development by a Chinese University (Fudan University, 2021). The combination of PLA fabric and luminous fibre can show a real-time heat map of the patient's body and can be washed and reused (Fudan University, 2021; Sun, 2011). Generally, blankets can be washed about 50 times before retirement. While this is not a perfect solution, it produces 50 times less garbage than traditional disposable medical blankets (Sun, 2011). Once the blanket has expired, it can be shredded and transferred to an industrial compost facility to biodegrade. The Smart Blanket will use the same manufacturing methods described in their article (Fudan University, 2021). The thermal sensors will also be integrated into a second conductive fibre which could use carbon nanotube technology to connect sensors to a power source (Baeg & Lee, 2020). Again, like the luminous fibres, these conductive fibre/heat sensors will be woven into the polyester fabric (Fudan University, 2021)

Smart Mattress

Advancements in the medical field may come from other industries. For example, a bicycle component brand named Fabric, based out of England, adapted technology from the footwear industry to make padding for their bicycle saddle (Fabric, n.d.). The three-piece construction consists of a nylon base, topped with an injection moulded TPU flexible pyramid layer, and capped with a smooth and durable TPU layer, see Figure 4.

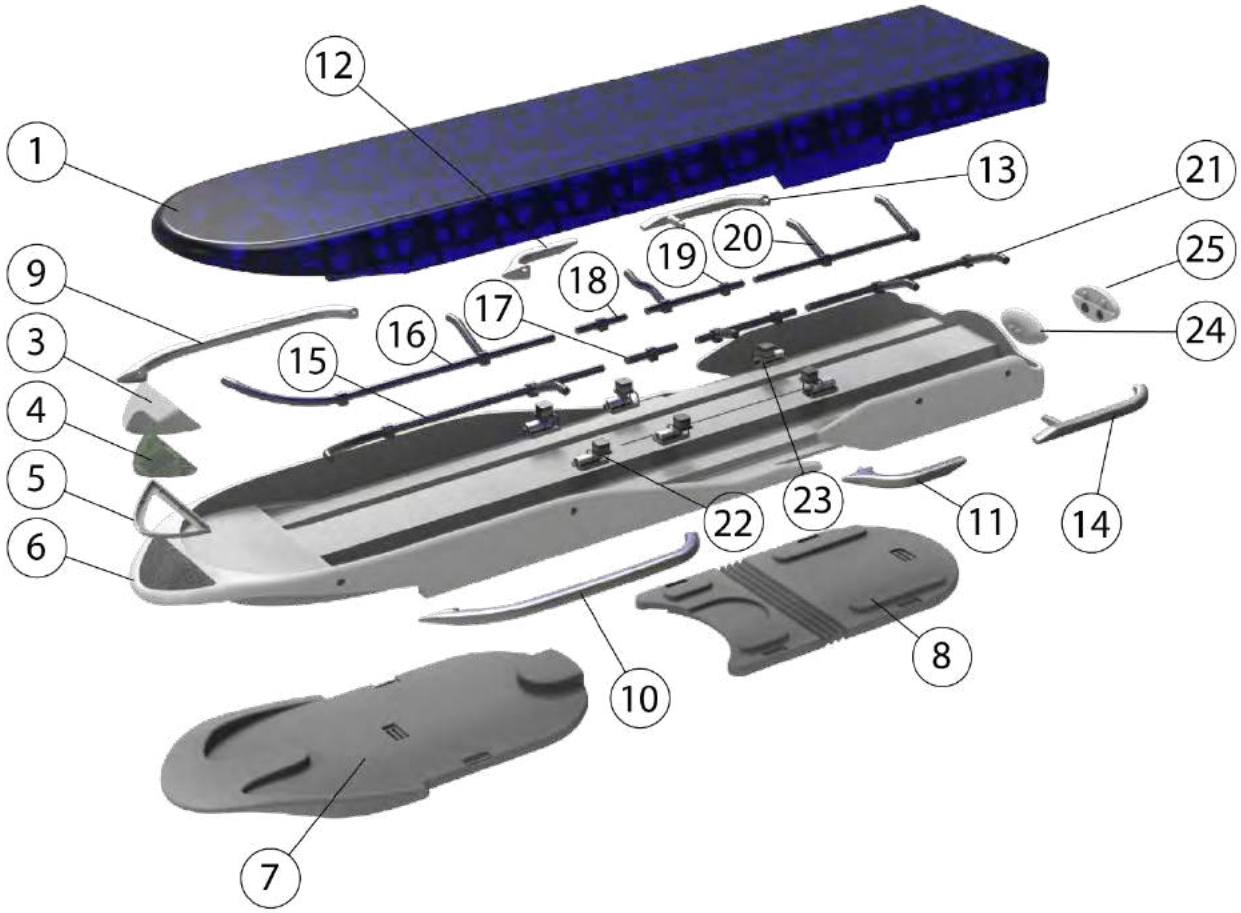
Figure 97 - Fabric Cell Elite Round Saddle has a three-piece construction (Fabric, n.d.)

This three-piece design is easily manufacturable, air type, and can be more easily separated into its component parts and recycled. This bicycle saddle technology can be adapted for the mattress. To adapt the saddle design to the mattress, the nylon base is replaced by a high durometer TPU so the entire mattress can stay flexible. Finally, Covestro's COV-207 Texin TPU can also be made biocompatible with skin contact (Covestro, n.d.) and can be mechanically or chemically recycled into new products afterwards (Ianelli, n.d.).

Docking Station

The Docking Station is affixed onto a paramedic's stretcher and is designed to receive and secure the Smart Mattress. The Docking Station must stand up to repeated bumps, heavy loads, sliding and disinfecting chemicals without significant wear and must stay flexible at a wide range of temperatures. Covestro's Desmopan TPU is a perfect fit for the task and can be Blow moulded into the correct shape (Covestro AG, n.d.).

5.2.3 Design Implementation



Part #	Description	Quantity	Material	Manufacturing Method	Price
1	Inner Mattress	1	Thermoplastic Polyurethane	Injection Molding	$3,500.00
2	Webbing - Connector Strapping	2	Nylon	Woven	$10.50
3	Screen Cover	1	Polycarbonate	Injection Molding	$10.00
4	Printed Circuit Board	1	FR-4/Copper	Prepreg Fibre Glass/Pick and Place	$10.00
5	Screen Mount	1	Polypropylene	Injection Molding	$10.00
6	Outer Mattress	1	Thermoplastic Polyurethane	Injection Molding	$2,800.00
7	Front Piece of Docking Station	1	High Durometer Thermoplastic Polyurethane	Blow Moulding	$1,785.00
8	Rear Piece of Docking Station	1	High Durometer Thermoplastic Polyurethane	Blow Moulding	$1,785.00
9	Left Front Handle	1	Brushed Steel	Steel Hydroforming	$225.00
10	Right Front Handle	1	Brushed Steel	Steel Hydroforming	$225.00
11	Right Center Handle	1	Brushed Steel	Steel Hydroforming	$225.00
12	Left Center Handle	1	Brushed Steel	Steel Hydroforming	$225.00
13	Left Rear Handle	1	Brushed Steel	Steel Hydroforming	$225.00
14	Right Rear Handle	1	Brushed Steel	Steel Hydroforming	$225.00

5.3 Final CAD Rendering

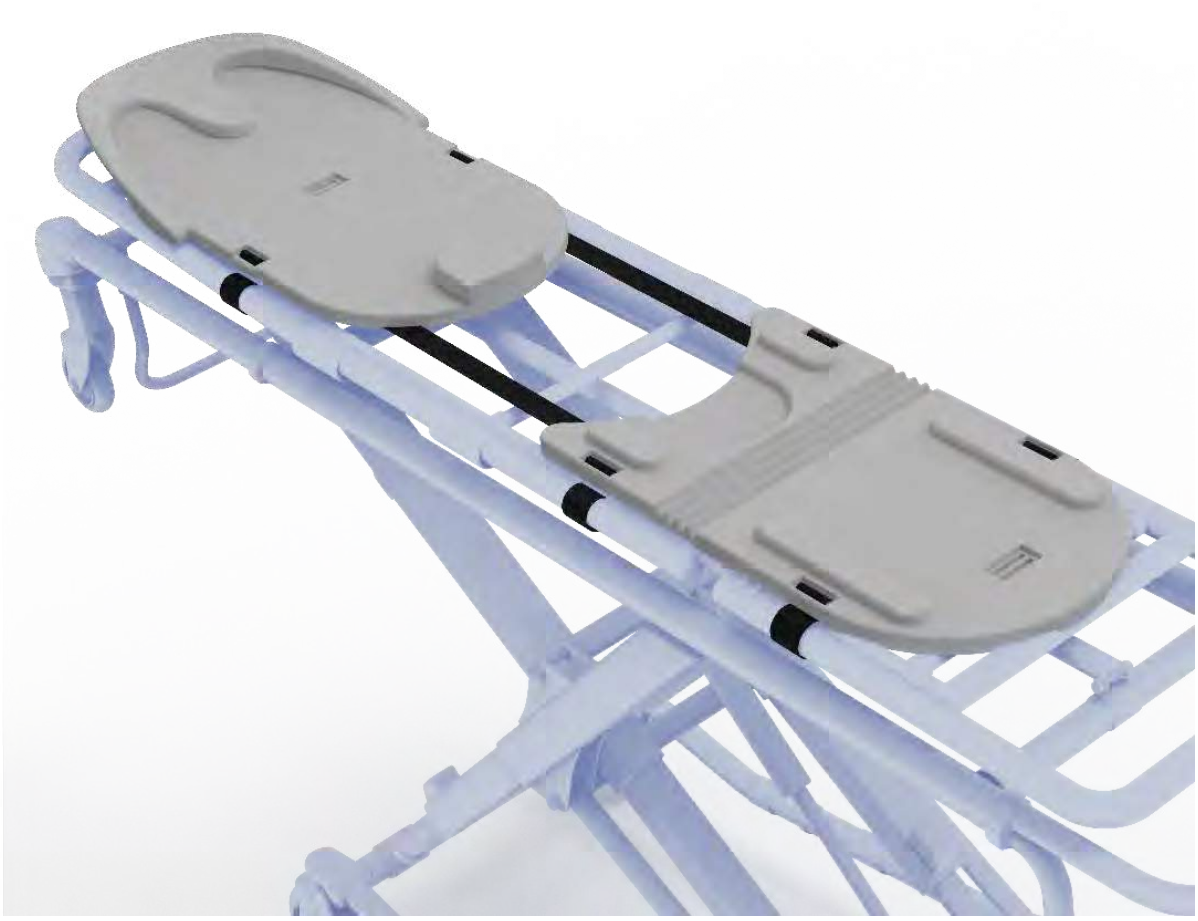


Figure 98 - The Docking Station can strap onto most existing stretchers

Figure 99 - Loading the ZEROCODE system into an ambulance

Figure 100 - A patient can be loaded onto a stretcher in most environments, all the while data is being collected by the system

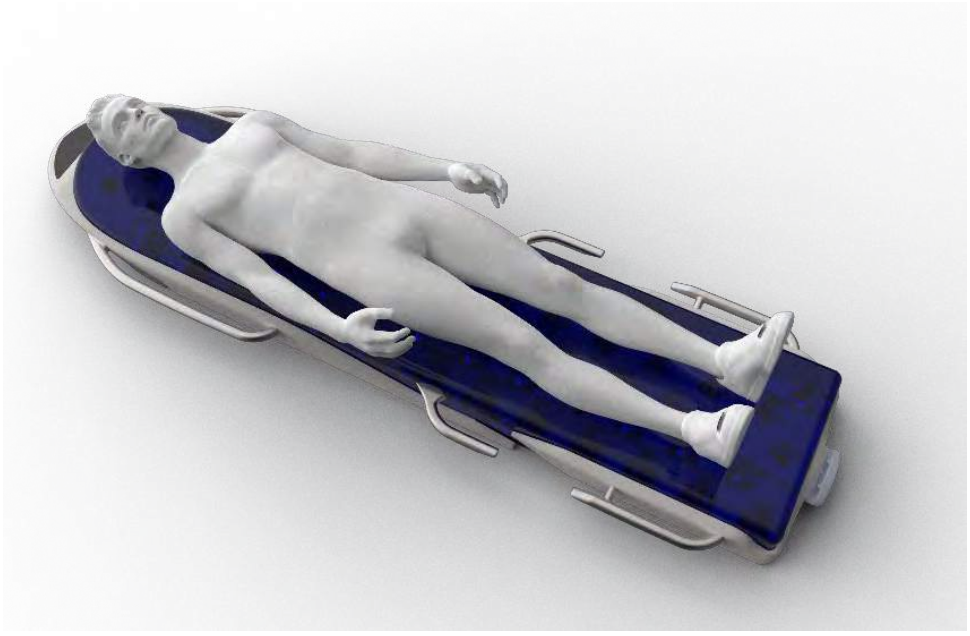


Figure 101 - Most patients fit perfectly onto the air-filled Inner Mattress

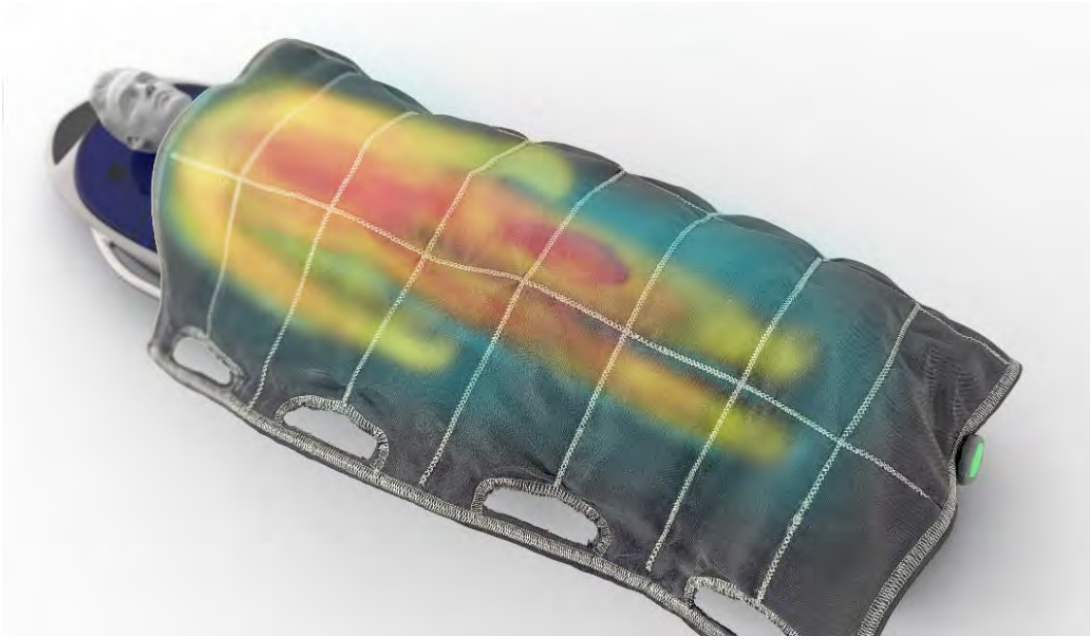


Figure 102 - The OLED fibers woven into the Smart Blanket allow the system to display a patient's real-time thermal signature

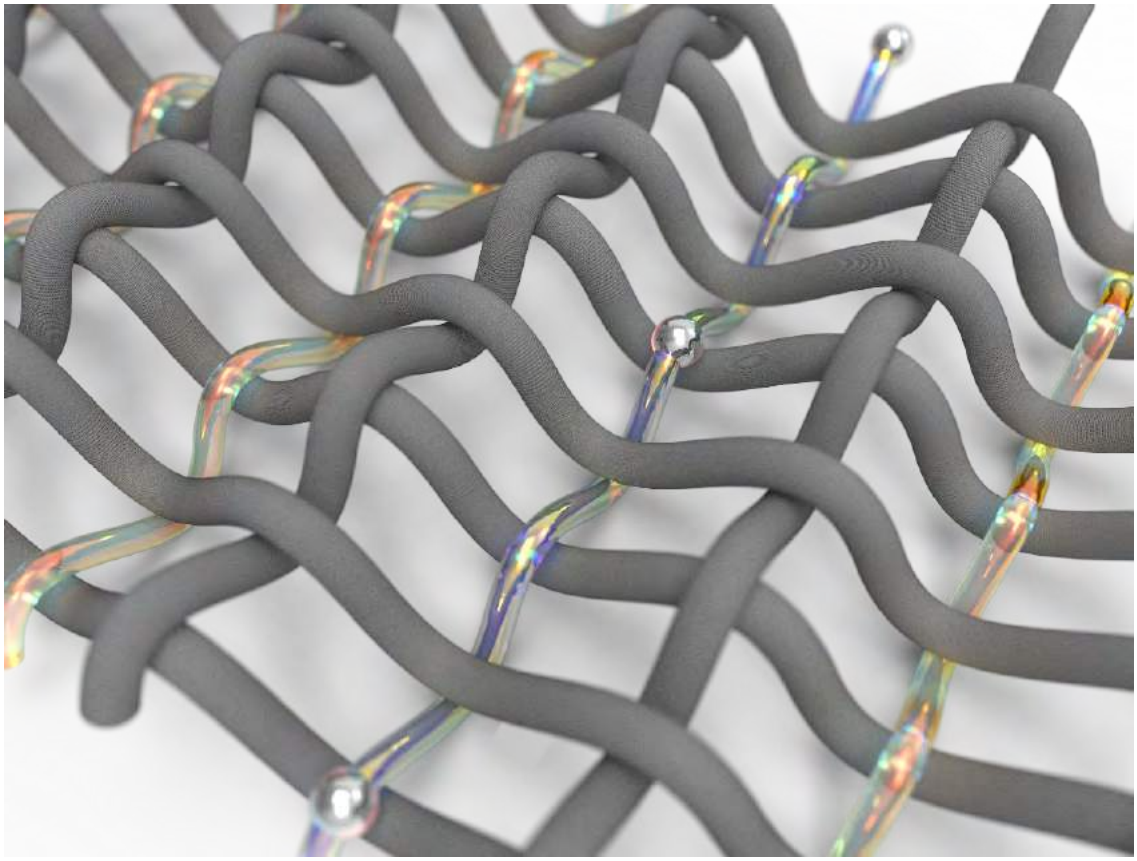


Figure 103 - Both OLED fibers and thermal/stretch sensors are woven into the PLA polyester blanket to enhance the blanket's capabilities

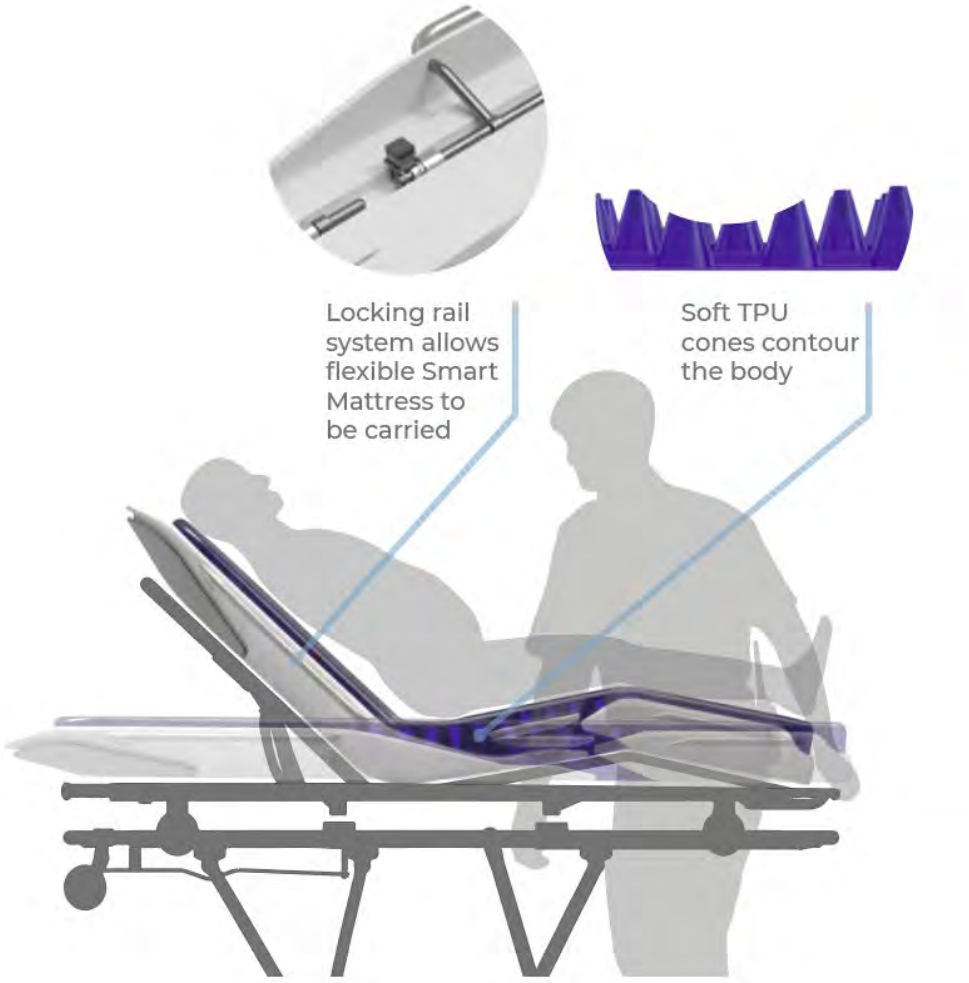


Figure 104 - The flexible TPU construction of the Smart Mattress allows it to conform to all the required patient positions

Figure 105 - The Smart Mattress features 6 stainless steel handles that allow paramedics to ergonomically lift the patient as well as easily clean the touch points

Figure 106 - Internal coupling systems allow the flexible mattress to lock horizontally, ensuring that Smart Mattress can safely be lifted while loaded

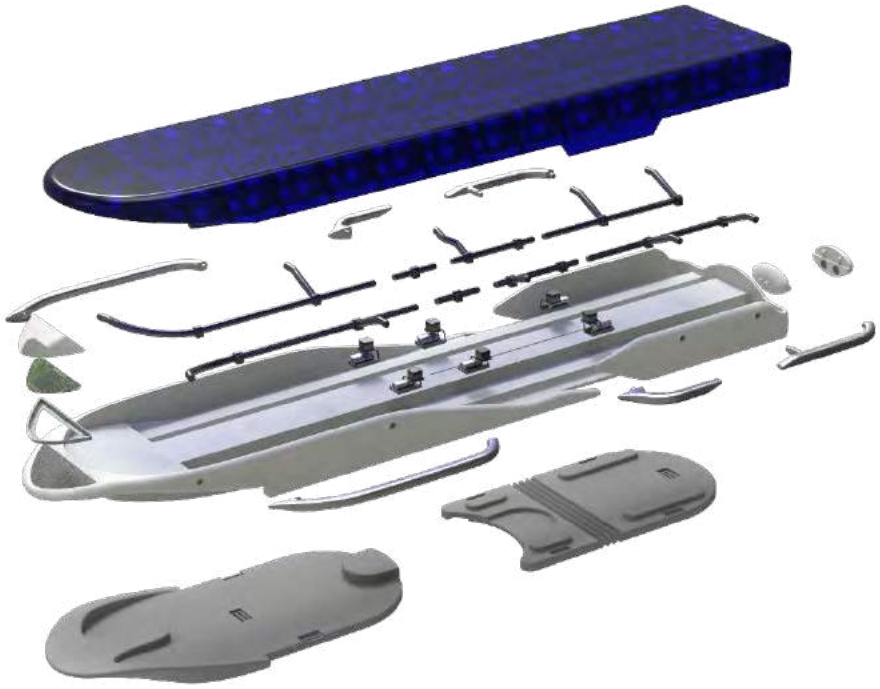


Figure 107 - The exploded view shows how all of the main components fit together

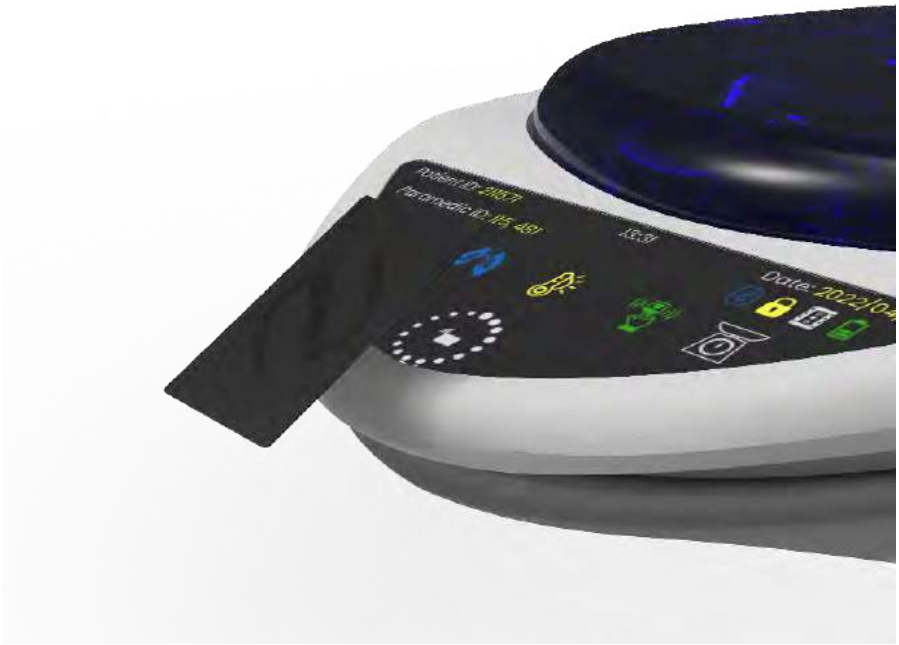


Figure 108 - All medical staff involved with emergent patient care recieve an access card allowing them access to patient's data

5.4 Physical Model

The bulk of the physical model was constructed from a combination of 3D prints, machine sewing, and laser cut acrylic. The intension was to create a “looks-like” model that represents the ZEROCODE system. The following figures display the physical model in multiple views.

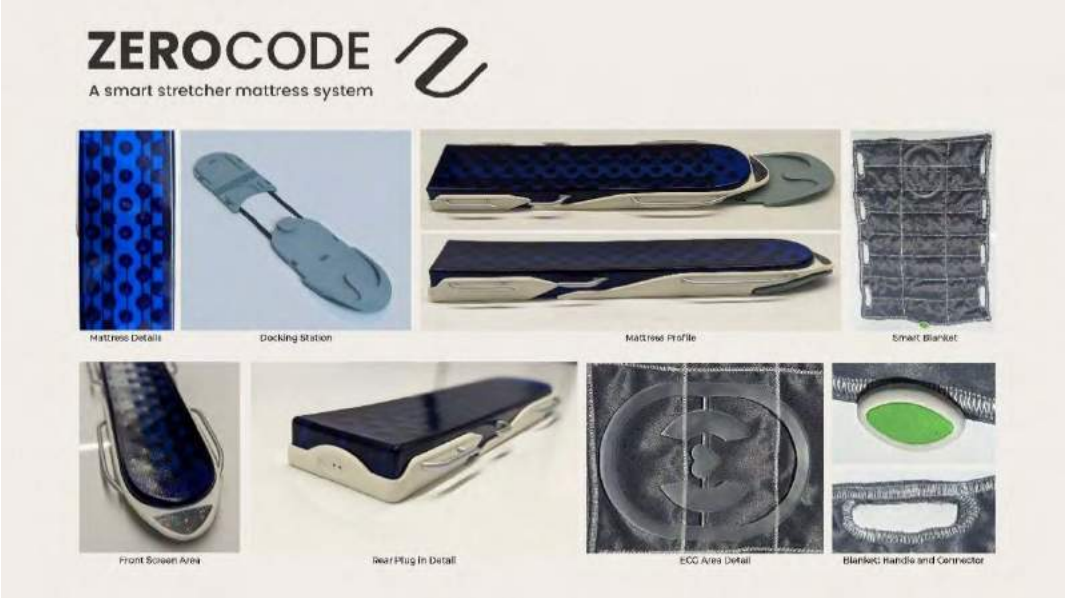
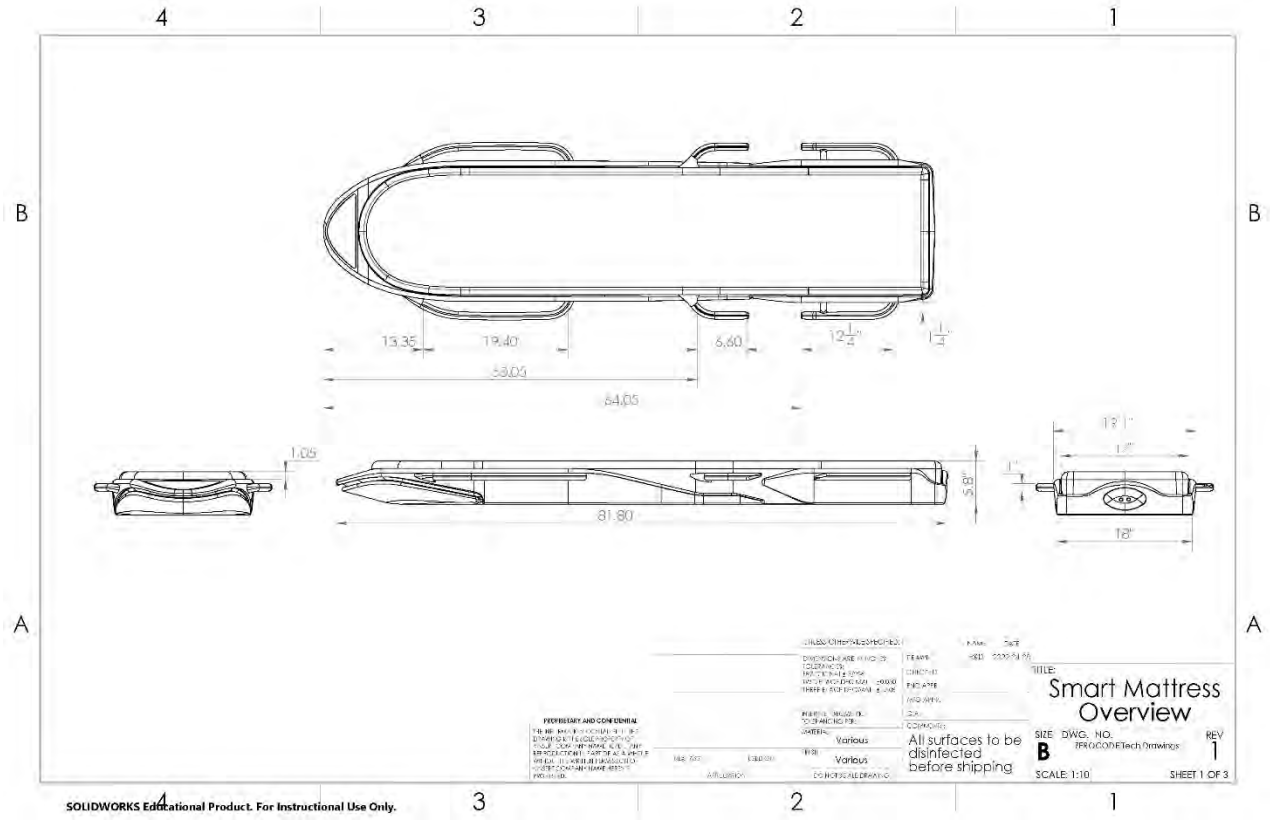


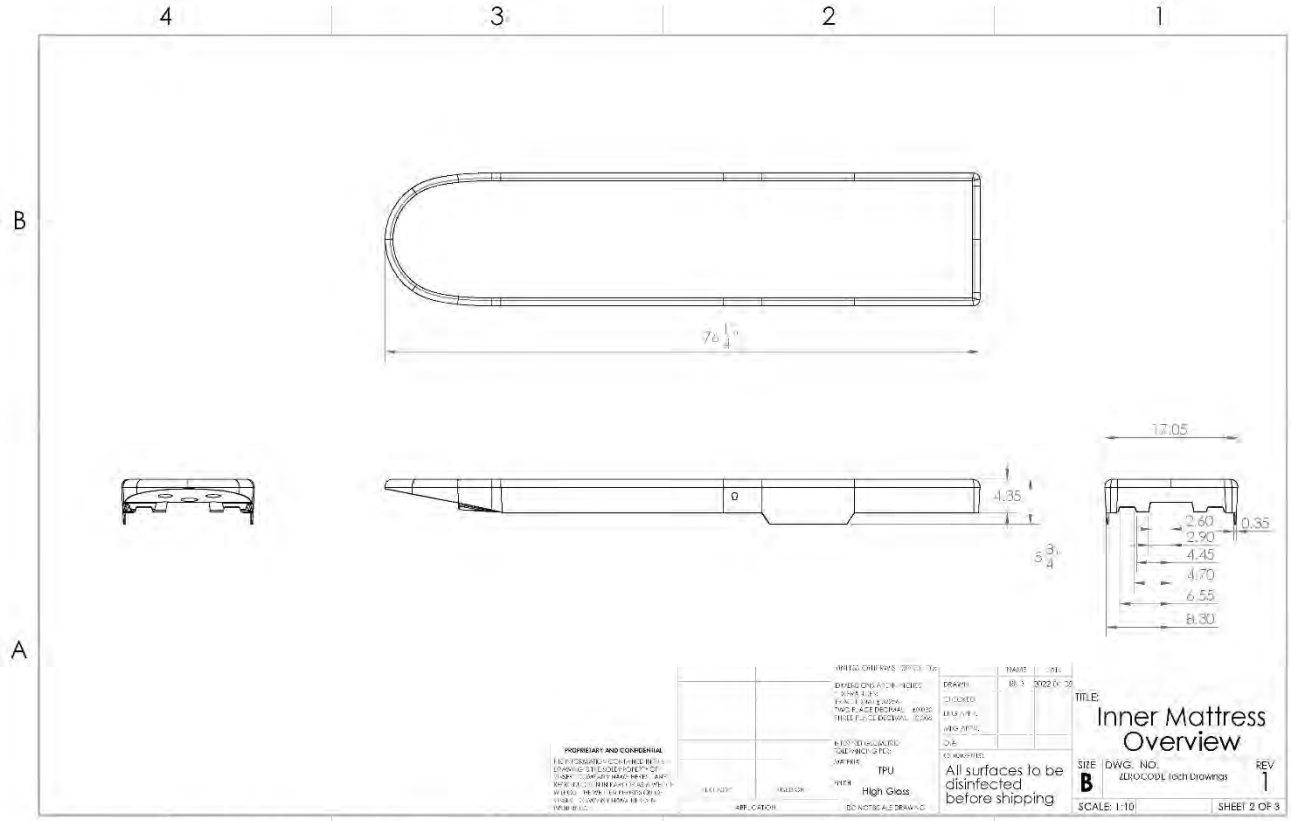
Figure 109 - A collection of photos of the physical model

Figure 110 - An additional collection of photos of the physical model

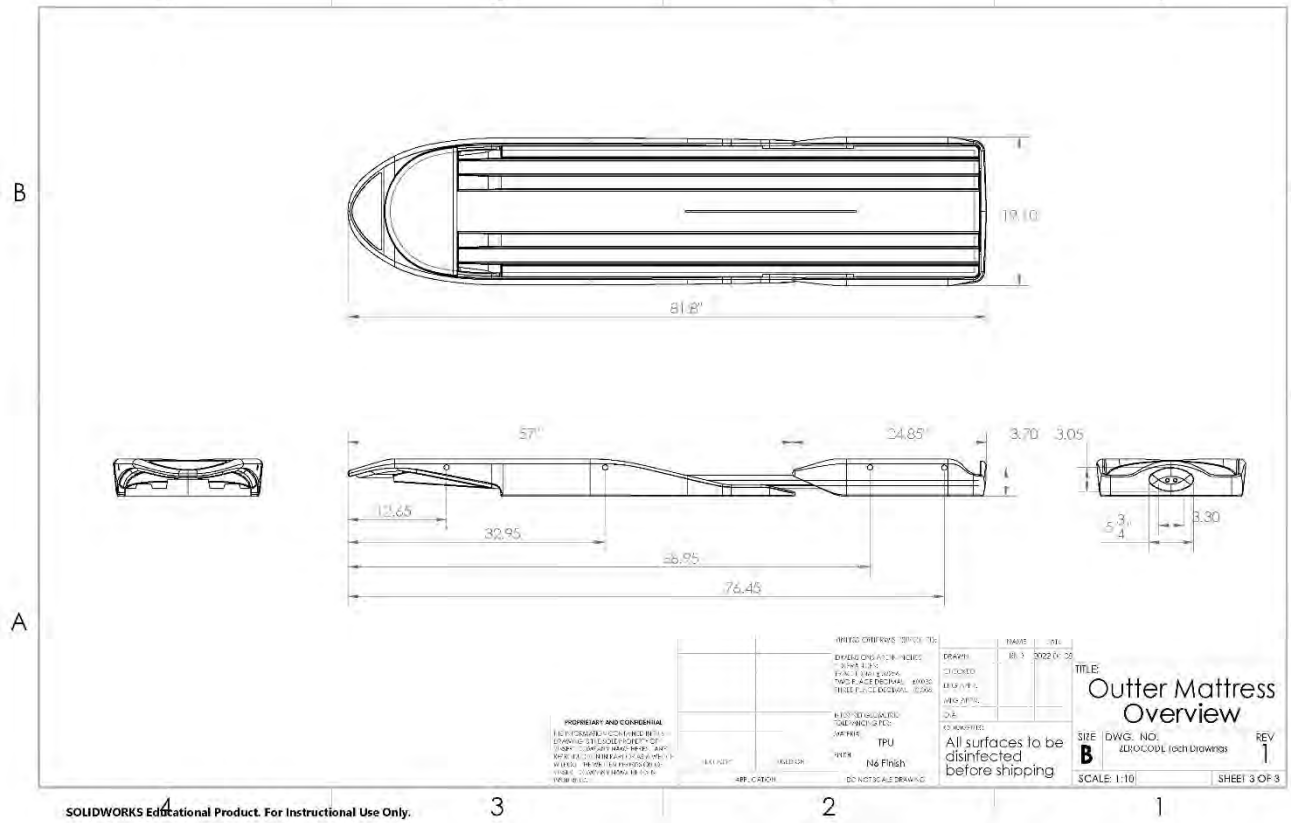
5.5 Technical Drawings

The following figures describe the ZEROCODE system on a technical level. The technical drawings outline only the main dimensions due to time and space restrictions. However, all components are within the Solidworks environment and therefore details dimensional of parts is available in needed.

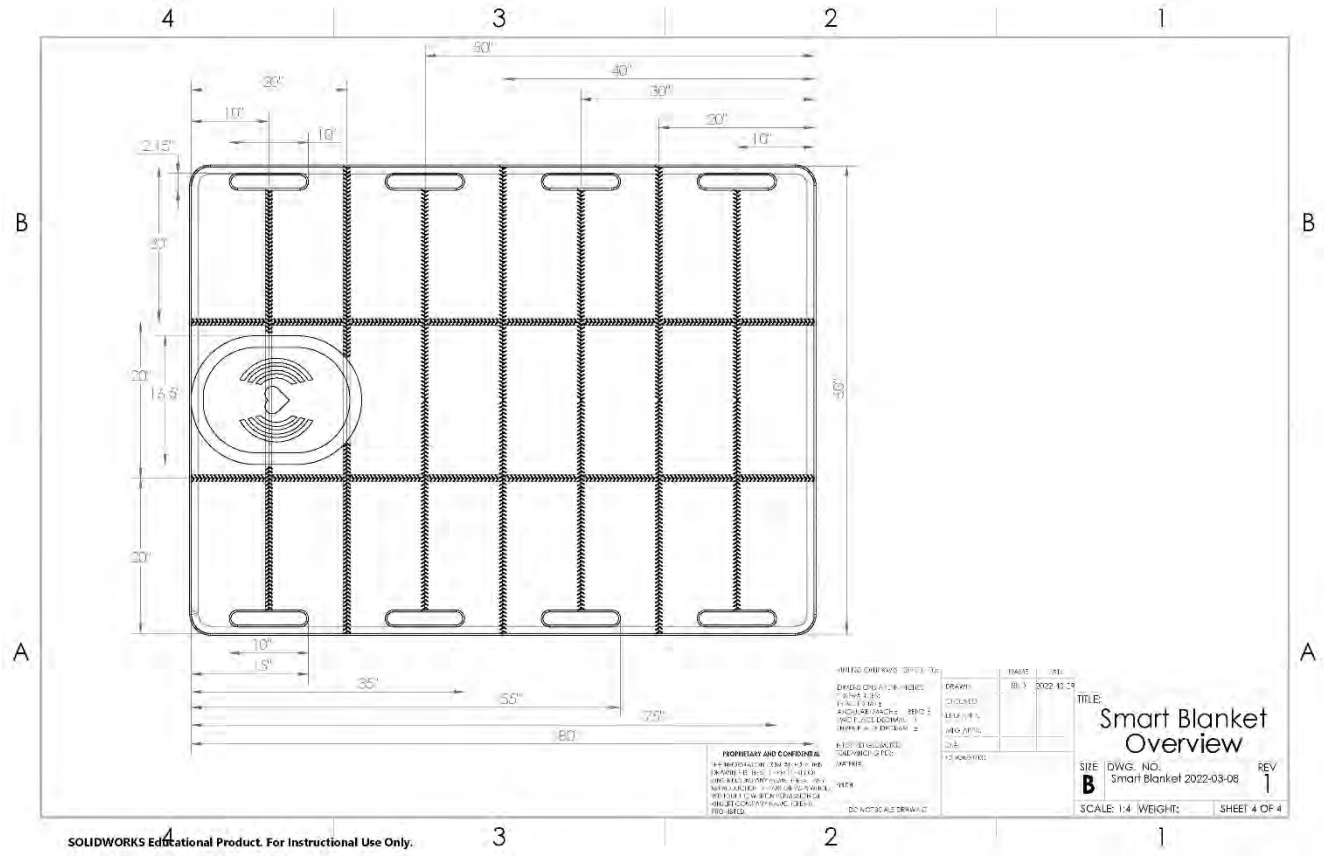




SOLIDWORKS Educational Product. For Instructional Use Only.



SOLIDWORKS Educational Product. For Instructional Use Only.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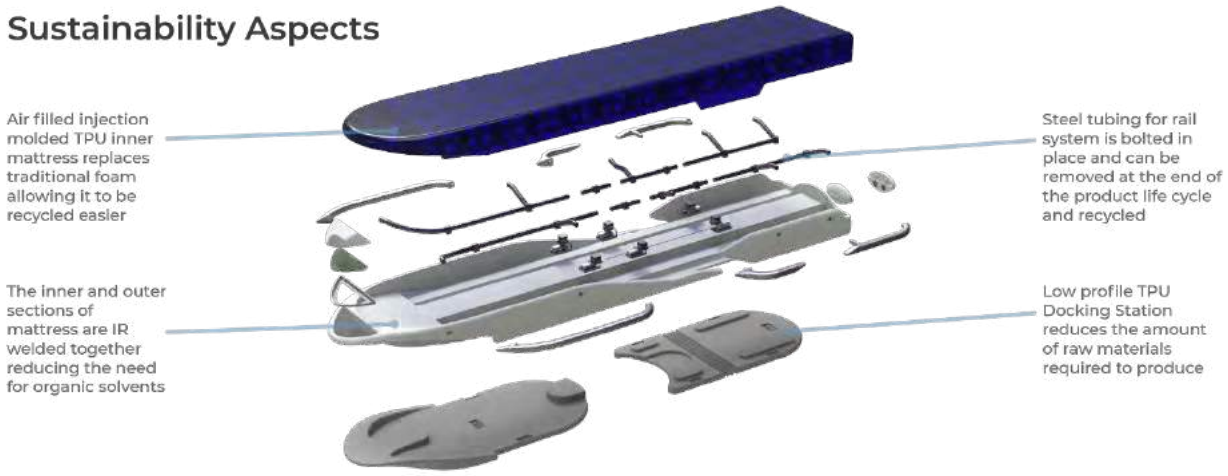
SHEET 4 OF 4
SOLIDWORKS Educational Product. For Instructional Use Only.

5.6 Sustainability



CHAPTER 6 Conclusion

When we experience a medical emergency, we are trained to pick up the phone and call 911 for help. Generally, time is of the essence in emergency situations and so first responders rush to our assistance. It is what we expect, it is what first responders strive for. However, demand for paramedics has increased in recent years, putting a strain on available resources. To further complicate the situation, emergency departments are often overcrowded, forcing paramedics to wait with their patients until the hospital can take over the care of the patient. If this wait time is over 30 minutes, it is classified as offload delay. When multiple ambulances experience offload delay a bottleneck situation can quickly occur. On busy days, ambulance coverage can become a serious concern. When ambulance availability drops to critical levels, the situation is termed Code Zero. These scenarios can be dangerous for vulnerable individuals who must wait for an ambulance to become available. This situation is complicated and requires a systemic solution to increase efficiencies in multiple areas.

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Appendix A – Discovery

Raw data from interviews will not be shared due to the confidentiality of the people interviewed. The following is the coding resulting from various interviews. Below is the initial interview with an Ontario critical care paramedic.

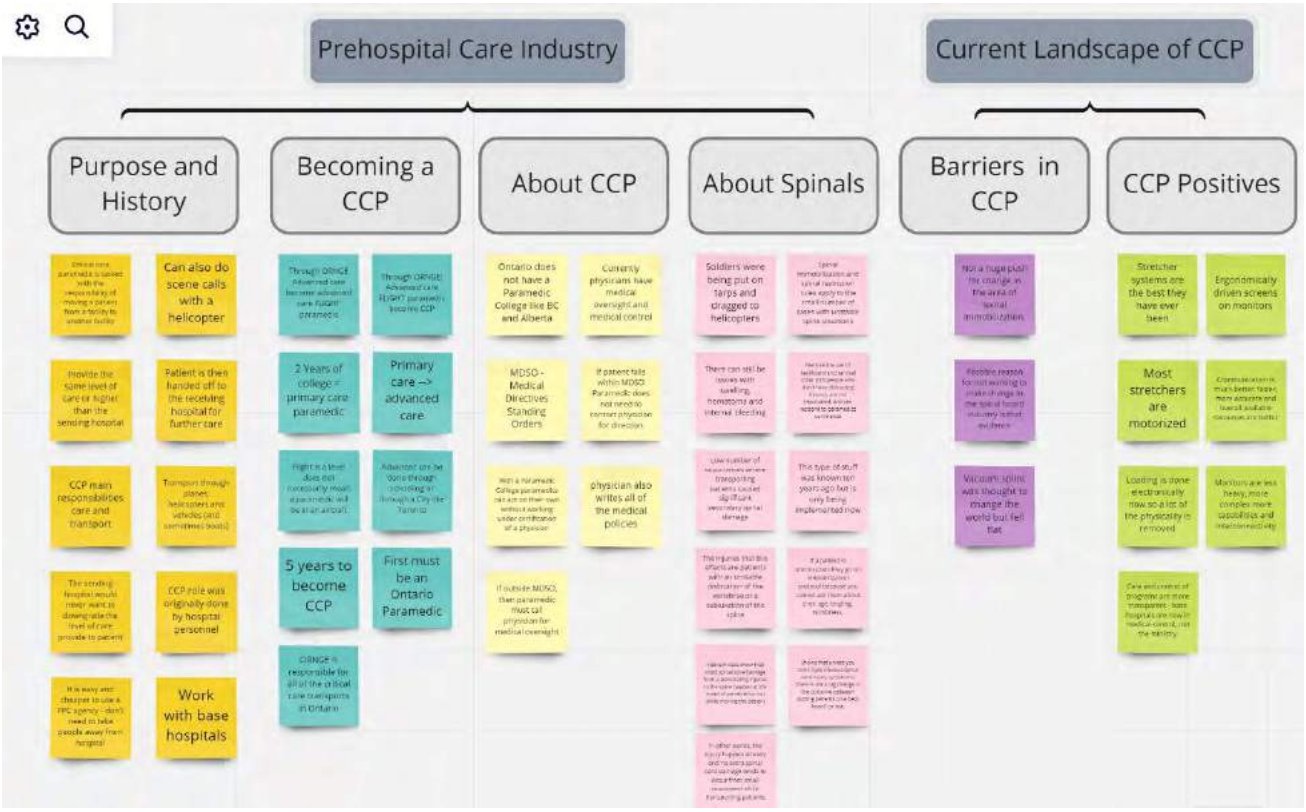


Figure A 1 – Initial Interview with Ontario Critical Care Paramedic

Below is an analysis of two different videos relating to the paramedicine industry. Both focus on critical care paramedics as this is where the project's initial direction. Both videos helped to establish some of the common tools used in the industry, how the tools are stored, the demeanor of paramedics and a basic introduction to what paramedics do on a shift.

Preliminary Video Search

Background
What is your objective for the thesis research?

- A Critical Care Paramedic (CCP) needs equipment to stabilize a patient during transportation to a hospital.
- The CCP needs to be efficient with time to provide the best chances of a full recovery for the patient in their care.
- The paramedic needs to protect themselves from ergonomic and biological hazards while maintaining a sufficient level of care for the patient.
- The user needs to efficiently transport the patient to a receiving hospital while doing as little secondary damage as possible.

Decision(s) to be made?

- What existing processes or tools used by a CCP to treat a patient can be improved to increase the probability of a complete or successful recovery?
- What new product or tool could allow the CCP to more efficiently stabilize the patient and transport them to a hospital for further care?

What information is required in the design research?

- From previous secondary research and existing knowledge, a paramedic of any level much first assesses the situation, stabilize the patient enough for loading, load, transport and then finally unload and hand off the patient to hospital staff.

Who is the target user?

- The target user of this thesis is a critical care paramedic.

Target background?

- M or F
- At least 18 (to start training) to the age of retirement (no specified age)
- There is a focus on paramedics in Ontario
- There is a focus on critical care paramedics
    - Primary Care Paramedic
    - Advanced Care Paramedic
    - Flight Paramedic
    - Critical Care Paramedic
- Video will allow for the understanding of context, behaviour, jargon, actions and outcomes of the target user.

Video One
URL: https://www.youtube.com/watch?time_continue=2&v=QnNFYhuuoLQ&feature=emb_logo
Title: Air Ambulance Medical Bag Walkthrough (Critical Care Helicopter)
Length: 17:25

Brief Description:
Sam, the presenter, is a critical care paramedic in Colorado, USA. He shares with the audience the contents of two bags that are always on the critical care helicopter. One bag is red with high-visibility yellow stripping and is called the scene bag. The scene bag contains everything needed by paramedics for the first 10 minutes on the scene of an accident. The other bag is fully black and is called the Interfacility Transfer (IFT) bag. Both bags are the same model but contain different equipment inside. Each bag has a main compartment and three pockets around the outside of the bag.

The pockets of the **red/yellow scene bag** contain the following:

- Top pocket: controlled substances (fentanyl, ketamine, etc.)
- Side Pocket 1: Blood administration devices (tubing, plasma, IV kit, Saline, etc.)
- Side Pocket 2: IO Drill, needles, glucometer
- Under Top Pocket: Various Gauzes and tourniquet

The main compartment contains six cells, each with a specific role to play in patient care:

1. Adult Airway
2. ACLS (Advanced Cardiovascular Life Support) resuscitation medication
3. Emergency backup airway
4. Adult and Pediatric Glide Scope Covers
5. Pediatric Airway bag
6. GlideScope laryngoscope (Helps to place a breathing tube)

Within the main compartment there is at the bottom used containing hard objects:

- “Mac and Miller” Laryngoscope blades
- Other airway intubation gear

The pockets of the **black IFT bag** contain the following:

- A balloon pump (for helping the heart pump)
- Medication transition and pump conversion equipment
- Blood warmer equipment
- Doppler heart monitor hook-up for the helicopter
- Test Lung and vent accessories
- Saline

Relevance to Thesis Topic:
This video was beneficial to understand what a critical-care paramedic may have at their disposal. It also puts into perspective the amount of gear required to transport critically ill patients, much of which is dedicated to a single task. This YouTube video also outlined some of the logic behind why items are stored where they are.

Video Two
URL: https://www.youtube.com/watch?v=xKtCREi9I7c&t=2s
Title: Medical Helicopter Tour | 911/CCT |
Length: 22:35

Brief Description:
Sam, the presenter, talks us through all the areas of a medical helicopter. Sam displays how a patient is loaded and unloaded into the aircraft from the left side. A procedure is called hot loading if the helicopter's rotors are spinning during the loading process. There are four positions inside the aircraft: the pilot's chair, the patient's cot, the left rear seat and the right rear seat. The person sitting in the right seat is responsible for preparing the medication and watching the monitor. The person on the left side is responsible for administering medications, checking on the patients and helping the pilot navigate. The space in between the left and the right seat is called the med-wall and contains the ventilator, oxygen supply, medication drip pump, impella machine and the balloon bump machine (both used to help the heart supply blood to the rest of the body. The patient and the crew use a second oxygen tree in front of the medwall (during high-altitude flights). Next to the oxygen tree is a Zoll monitor, blood warmer and suction module. A hanging fabric storage device holds important but less immediate items like batteries, extra syringes and tape. Finally, less used items are stored around the helicopter but outside of the cabin. Examples of these items are consist of PPE, cleaning supplies, vacuum splints and baby delivery equipment.
Relevance to Thesis Topic:
This video gave a detailed view of how the helicopter cabin is laid out. The video shows how the helicopter is tightly packed with little extra space. The knowledge of the available area will help design within the existing constraints. Additionally, becoming familiar with the devices used by paramedics will aid in the understanding of which connections may need to be available in a future product.

Video Three
URL:
https://www.youtube.com/watch?v=2eDCElcZQOo&list=PLUJtpOzaISf0fVy25vLK8C8VQHa3el0pp&index=6
Title: Unlucky Crash Leaves Motorcyclist With A Broken Neck | Helicopter ER S1 E5 |
Length: 44:04

Brief Description:
The video follows paramedics from the Yorkshire Air Ambulance on several calls around England. The paramedics help a mountain biker, a couple in a car crash, a motorcyclist, a farmer, and a hiker. In each scenario, the paramedics assessed the situation, ensure the patient is stabilized and then

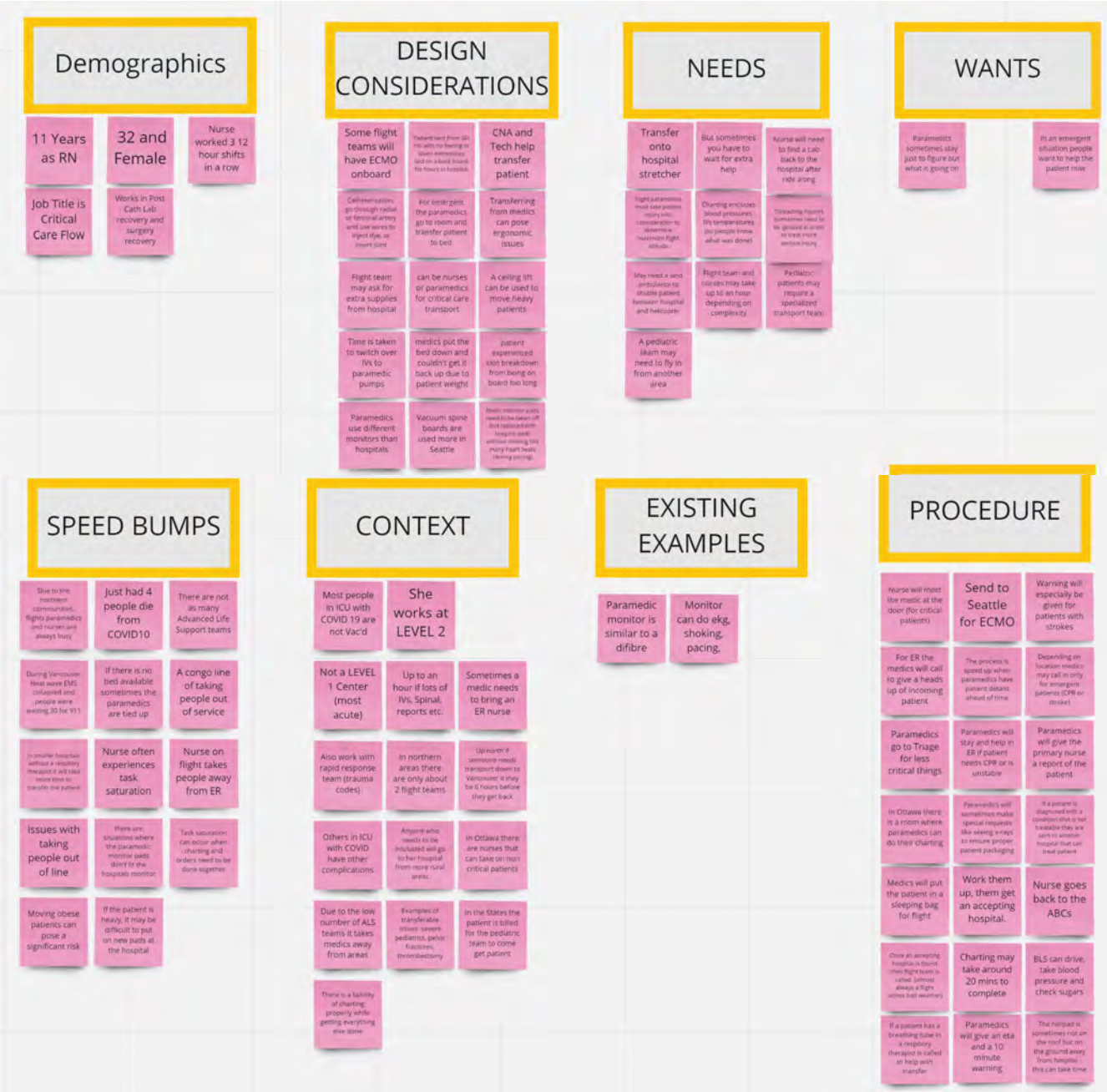
quickly moved towards the hospital. In almost every scenario, the paramedics opted to put the patient on a long spine board for transportation to the helicopter. Although the narrator described each situation in a far more dramatic light than the paramedic's actions let on, each case was serious with three of the stories concluding with the patient having a fractured or broken spine.

Relevance to Thesis Topic:
The video showed various technics for extracting a patient from the scene of the accident. In cases like the mountain biker or the hiker, a specialized mountain rescue team was called to help the patient out. The video also should the delicate and time-consuming nature of getting a patient out of a vehicle with a suspected spinal injury.

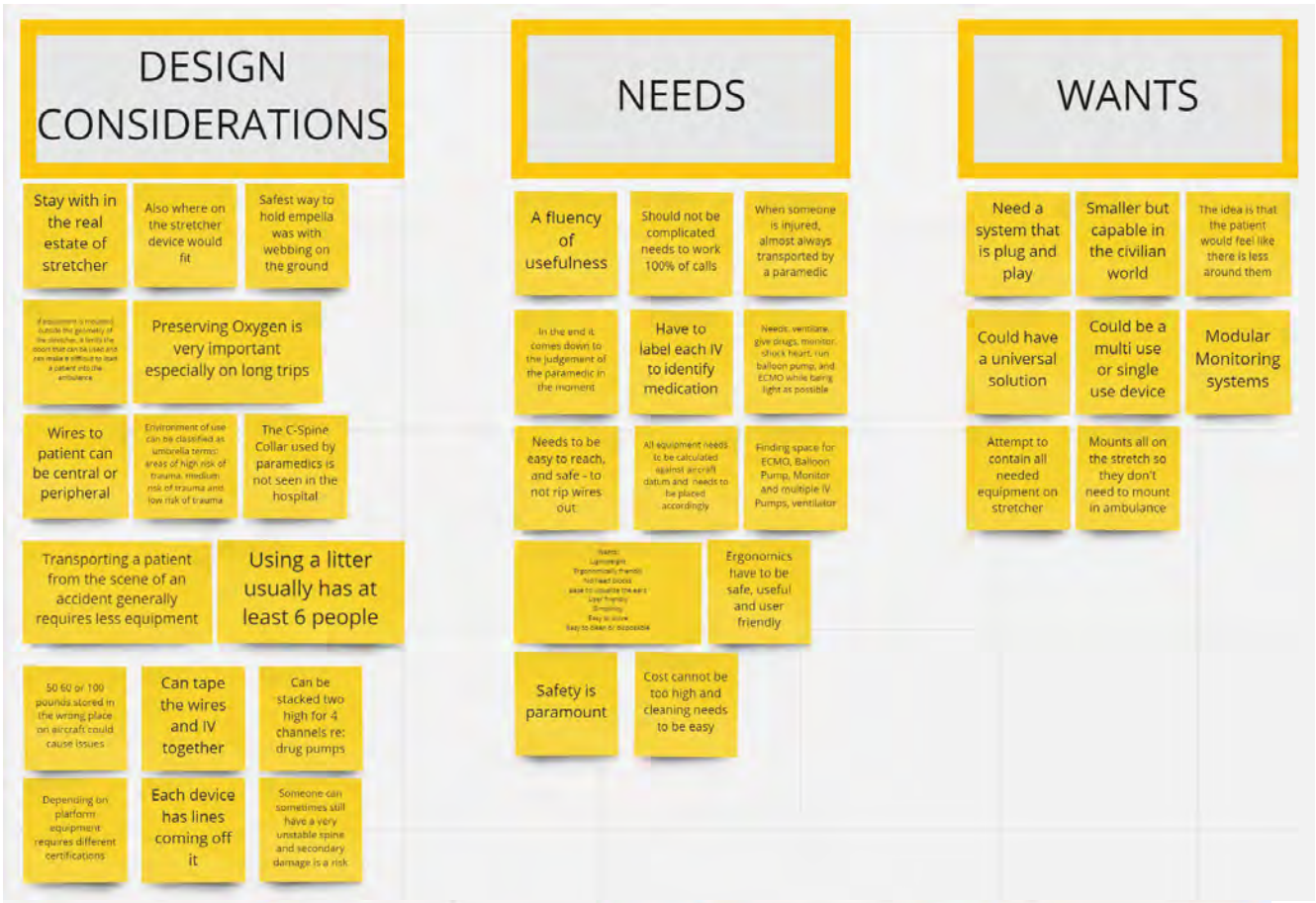
Appendix B – Contextual Research (User)

The following information was coded from original transcripts. To conform to the confidentiality agreement between the interviewer and interviewee, only the coded content will be displayed. In addition to the coded information below, there were a few informal interviews with paramedic students which did not get coded or recorded but was used to build context in the interviewer's work.

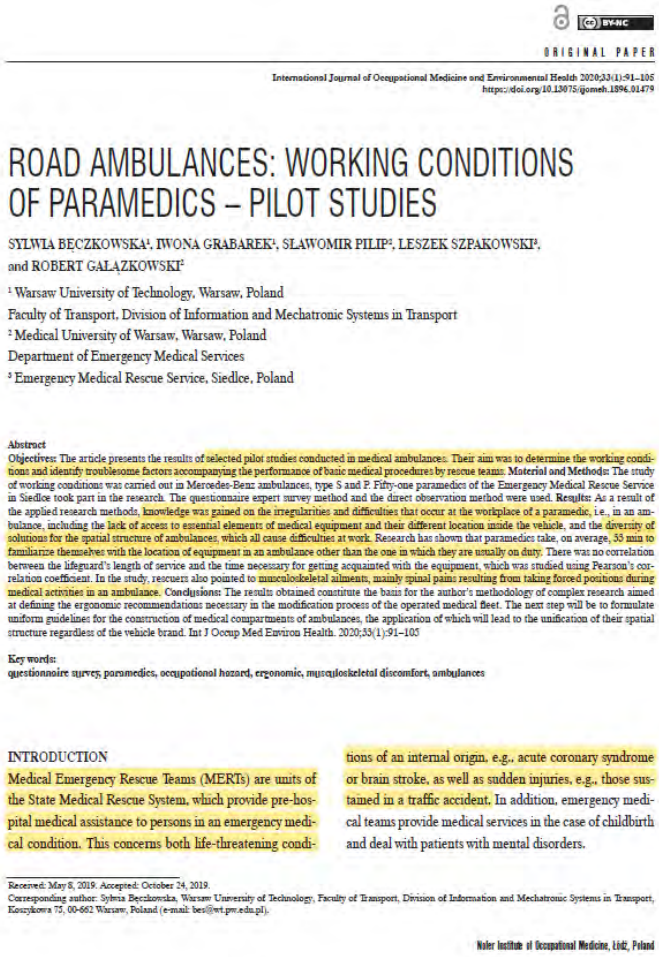
Emergency Room Nurse



Critical Care Paramedic Interview 2



Below is one of the many reports used to gain an understanding of the working condition of the user group (paramedics). The green sticky below are some notes that were taken about report.



ORIGINAL PAPER

International Journal of Occupational Medicine and Environmental Health 2020;33(1):91–105
https://doi.org/10.13075/ijomeh.1896.01479

ROAD AMBULANCES: WORKING CONDITIONS OF PARAMEDICS – PILOT STUDIES

SYLWIA BĘCZKOWSKA[1], IWONA GRABAREK[1], SŁAWOMIR PILIP[2], LESZEK SZPAKOWSKI[3], and ROBERT GAŁĄZKOWSKI[2]

[1] Warsaw University of Technology, Warsaw, Poland
Faculty of Transport, Division of Information and Mechatronic Systems in Transport
[2] Medical University of Warsaw, Warsaw, Poland
Department of Emergency Medical Services
[3] Emergency Medical Rescue Service, Siedlce, Poland

Abstract

Objectives: The article presents the results of selected pilot studies conducted in medical ambulances. Their aim was to determine the working conditions and identify troublesome factors accompanying the performance of basic medical procedures by rescue teams. **Material and Methods:** The study of working conditions was carried out in Mercedes-Benz ambulances, type S and P. Fifty-one paramedics of the Emergency Medical Rescue Service in Siedlce took part in the research. The questionnaire expert survey method and the direct observation method were used. **Results:** As a result of the applied research methods, knowledge was gained on the irregularities and difficulties that occur at the workplace of a paramedic, i.e., in an ambulance, including the lack of access to essential elements of medical equipment and their different location inside the vehicle, and the diversity of solutions for the spatial structure of ambulances, which all cause difficulties at work. Research has shown that paramedics take, on average, 55 min to familiarize themselves with the location of equipment in an ambulance other than the one in which they are usually on duty. There was no correlation between the lifeguard's length of service and the time necessary for getting acquainted with the equipment, which was studied using Pearson's correlation coefficient. In the study, rescuers also pointed to musculoskeletal ailments, mainly spinal pains resulting from taking forced positions during medical activities in an ambulance. **Conclusions:** The results obtained constitute the basis for the author's methodology of complex research aimed at defining the ergonomic recommendations necessary in the modification process of the operated medical fleet. The next step will be to formulate uniform guidelines for the construction of medical compartments of ambulances, the application of which will lead to the unification of their spatial structure regardless of the vehicle brand. Int J Occup Med Environ Health. 2020;33(1):91–105

Key words:
questionnaire survey, paramedics, occupational hazard, ergonomic, musculoskeletal discomfort, ambulances

INTRODUCTION

Medical Emergency Rescue Teams (MERTs) are units of the State Medical Rescue System, which provide pre-hospital medical assistance to persons in an emergency medical condition. This concerns both life-threatening conditions of an internal origin, e.g., acute coronary syndrome or brain stroke, as well as sudden injuries, e.g., those sustained in a traffic accident. In addition, emergency medical teams provide medical services in the case of childbirth and deal with patients with mental disorders.

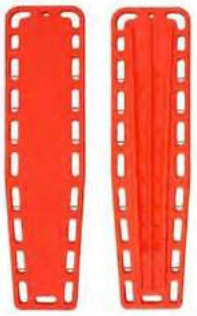
Received: May 8, 2019. Accepted: October 24, 2019.
Corresponding author: Sylwia Bęczkowska, Warsaw University of Technology, Faculty of Transport, Division of Information and Mechatronic Systems in Transport, Koszykowa 75, 00-662 Warsaw, Poland (e-mail: bes@wt.pw.edu.pl).

1.A significant portion of patient medical intervention was provided while the vehicle is in transit to the hospital
2. Access to equipment was rated as bad and paramedic seat comfort was rated as bad or very bad
3. Lower back was most frequently mentioned a s a type of posture stress in a pain. This is along with shoulders and neck
4. a pilot study created a prototype ambulance interior with 2 adjustable chairs, more ergonomic equipment cabinets , swivel base for chairs and a patient loading system. lighting and communication panels were put closer to the paramedics
5.The lack of fall protection devices for paramedics while driving an ambulance, difficulty access to the patient and difficult access from a sitting position to the necessary equipment and medicine have been demonstrated

Appendix C – Field Research (Product)

The following is the benchmarking of existing products within the paramedicine industry. Most of the products are either involved in moving the patient and, or immobilizing the patient. This is by no means an exhaustive list, however, it provides a sufficient starting point to further explore other products.

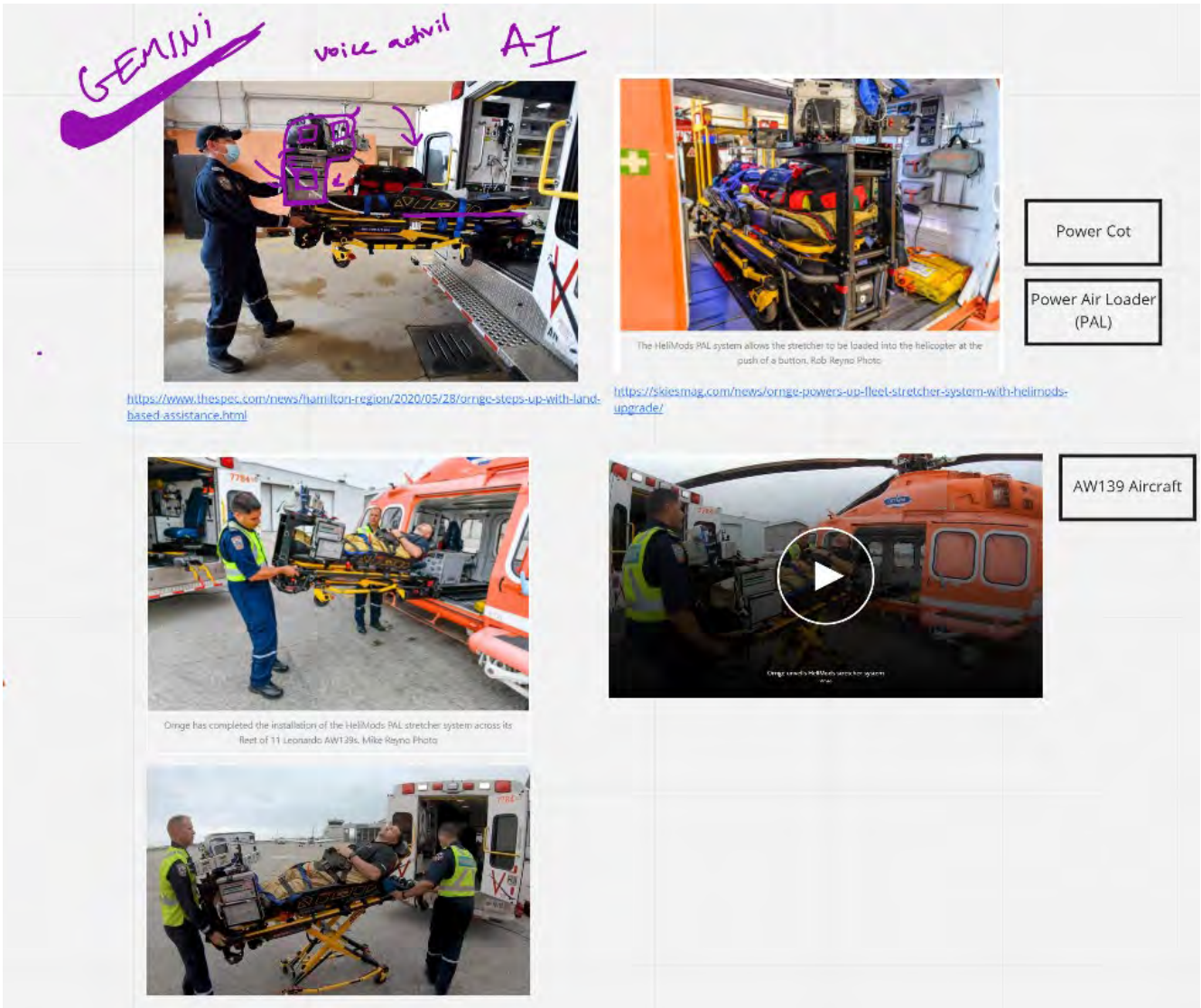
Bench Marking

User	Product
Long Spine Board	 **Plastic Long Spine Board** **Material:** Polyethylene **Dimensions:** 72" X 18" **Price:** $169.95 US **Features:** - Foam filled - Compatible with most head immobilization devices - Can be worn during x-ray **Benefits:** - Non-porous surface/anti-microbial - Easy to clean - Molded to cradle the body - Reduced number of pressure points **Drawbacks:** - Does not conform to the body - May cause secondary injuries in elder patients, and those with non-standard spine shape **https://safetyexpress.com/spinal-backboard-72-x-18-with-8-pins-polyethylene/**  **Wooden Long Spine Board** **Material:** Marine grade Okoume plywood, Polyurethane **Dimensions:** 72" X 18" **Price:** $584.00 US **Features:** - Compatible with most head immobilization devices - Can be worn during x-ray **Benefits:** - Classic appearance - Floats in water **Drawbacks:** - Splintering - Cracking over time - Potential for bacteria and viruses to live on surface - Generally not form fitting https://www.globalindustrial.ca/p/wood-fg-spineboard?infoParam.campaignId=T9F  **Plastic/Metal Scoop Stretcher** **Material:** High Density Polyethylene **Dimensions:** 72" X 18" **Price:** $345.77 CAD **Features:** - Splits apart to allow spine board to be inserted under patient from each side requiring minimal movement of patient - Leg section can fold up for easier storage - Adjustable leg section **Benefits:** - Scoop style spine board to better patient and handler ergonomics - Easy to store - Possible reduction of secondary injury due to movement **Drawbacks:** - Price - Weight restriction - Limited compatible head immobilization devices **https://www.kempusa.com/ems/patient-immobilization/spineboards-stretchers/buy-13-kemp-usa-scoop-stretcher-yellow-10-988-yel.html**

Cervical Collar		**Cervical Collar with Trachea Access** **Material:** Polyethylene, nylon, polyurethane, cotton **Dimensions:** Adults **Price:** $140.00 CAD **Features:** - Can be worn during x-ray - Access to the trachea - Height adjustment technology **Benefits:** - Can be put on while patient is laying down - Can be used long term **Drawbacks:** - May crack with heavy use - Can slide up over a patients chin while asleep or lying down https://spasupply.ca/products/procare-vista-collar2?variant=29383676428406&cv=CAD&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&gclid=CjwKCAjw4qCKBhAVEiwAkTYsPBFqkqGNiE0iRWsOQCdjkgS0DGMitu1tMEVSeZGisq7_pQHunSBZERoCP74QAvD_BwE **Pediatric Servical Collar with Body Harness** **Material:** Polyethylene, Nylon, Polyurethane Cotton **Dimensions:** Pediatric **Price:** $241.00 US USD **Features:** Can be worn during x-ray Access to the trachea Height adjustment technology **Benefits:** Prevents migration of the cervical collar **Drawbacks:** Difficult to install while lying down https://www.aspenmp.com/aspen-pediatric-cto.html https://frontlinemedicalmil.com/wp-content/uploads/2020/12/VA_Aspen-Product-Catalog.pdf
		
Vacuum Mattress		**PVC Vacuum Mattress (VMED)** **Material:** Isolative and cold-resistive PVC **Dimensions:** 80cm X 88cm X 80 cm **Price:** $575 CAD **Features:** Double-action vacuum pump Compatible with X-Ray/MRI Can be worn during x-ray **Benefits:** Lightweight Packable Formfitting Thermal insulator **Drawbacks:** May cause pressure ulcers Requires the storage and use of foot pump Takes about 2/3 more time than a rigid spine board https://shopee.ph/VMED-Vacuum-Stretcher-i.45367544.1883564499 **Polyurethane Fabric Vacuum Mattress** **Material:** Durable poly urethane fabric **Dimensions:** 7 ft long **Price:** $2099 US **Features:** - 8 lifting handles - Compatible with X-Ray/MRI - Can be worn during x-ray Multiple chambers to allow for proper distribution of beads **Benefits:** - Lightweight - Packable - Formfitting - Thermal insulator **Drawbacks:** - May cause pressure ulcers - If seal is not perfect, the device becomes useless - Takes more time to stabilize patient than a traditional spine board https://www.boundtree.com/immobilization-splinting/vacuum-mattresses-pumps/air-transport-vacuum-spine-board-set-7ft/p/MT90002
		

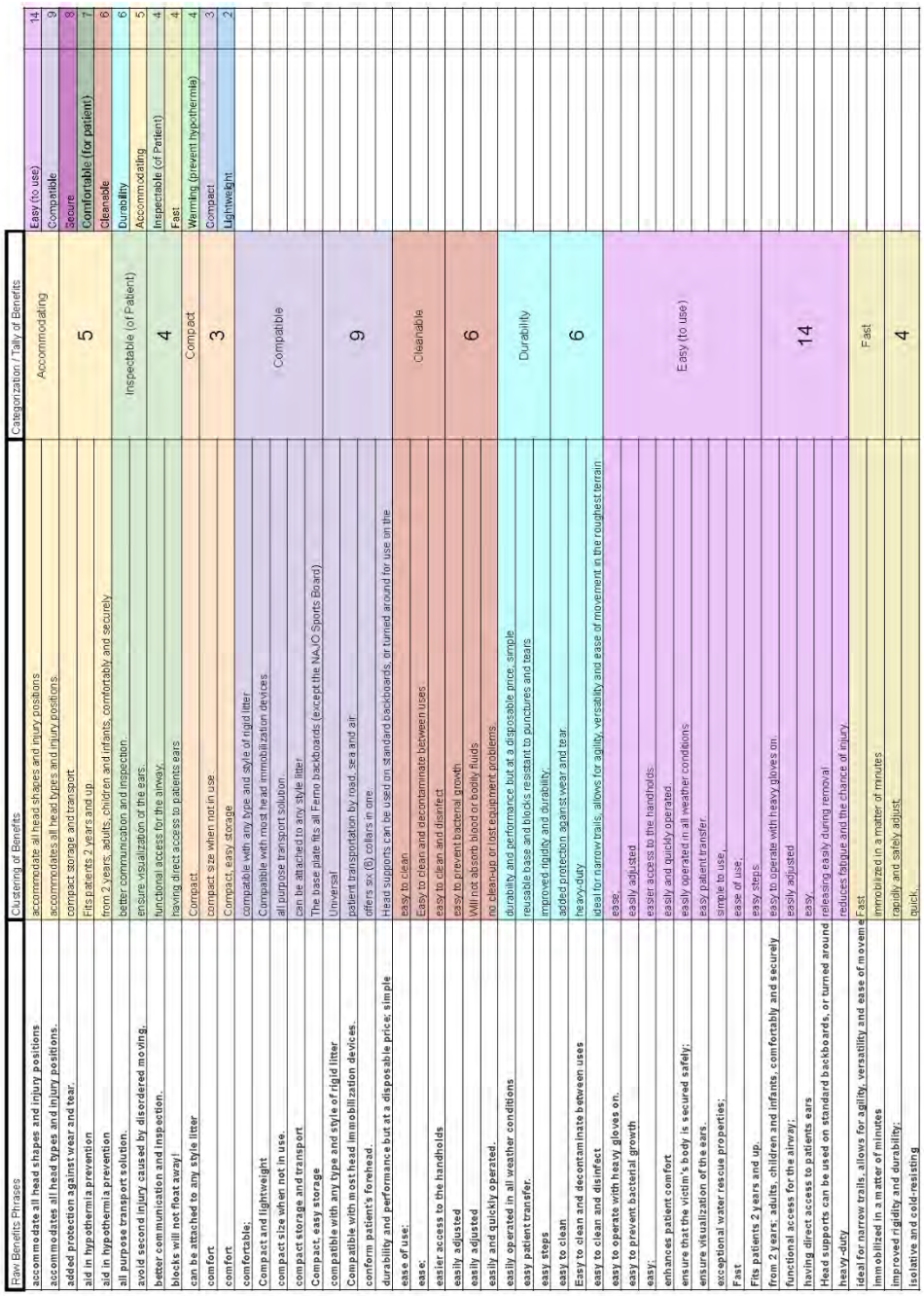
Head Immobilization (Head Blocks)		**Disposable Head Bocks (Laerdal Headbed II)** **Material:** Wax coated Cardboard, foam(?) **Dimensions:** One size fits most **Price:** $8.00 US **Features:** - Stores flat - Foam head pad - Compatible with X-Ray/MRI - Fits most spine boards **Benefits:** - Cheap - Fast - Water resistant - Access to the ears **Drawbacks:** - Cannot be reused - Not water proof **https://www.boundtree.com/immobilization-splinting/head-immobilizers/headbed-ii-head-immobilizer-universal/p/260209** **Adjustable Head Immobilizers (Laerdal Speedblocks)** **Material:** High-density Polyethylene **Dimensions:** One size fits most **Price:** $575 CAD **Features:** - Reusable with easy to clean surfaces - Ensure comfort for patient - Ear holes - Ages 2 and up - Fits most spine boards **Benefits:** - Easy to clean - Fast to adjust - Latex free - Access to the ears **Drawbacks:** - Different mounting system than users typicaly use requiring some time to get used to the product **https://laerdal.com/ca/products/medical-devices/immobilisation/speedblocks-head-immobilizer/** **https://www.watersafety.com/store/emergency-equipment/laerdal-speedblocks-head-immobilizer.html** **Vinyl Coated PVC/NBR Foam head immobilizers** **Material:** Vinyl-coated PVC/NBR closed foam and nylon straps **Dimensions:** One size fits most **Price:** $ 184.14 **Features:** Universal attachment base Foam head pad Fits both standard and scoop backboards **Benefits:** Simple Easy to clean Compatible with radiation imaging Access to the ears **Drawbacks:** - Must be turned upside down to fit into some basket style stretchers - May not work with all stretchers/backboards **http://ferno.ca/index.php/product/445-universal-head-immobilizer/**
		
Offroad Extractions		**The Mule - Litter Wheels/Stretcher Carriers** **Material:** Aluminum Tubings, Nylon Webbing, Rubber, Steel **Dimensions:** 66 x 84 x 47 cm **Price:** 1353.97 CAD **Features:** - Large lightweight ATV wheel - Single-Wheel design allows for easy maneuverability through narrow trails - Universal Design - Can Fold down to about the size of the wheel - **Benefits:** - Robust design is good for snow, rain, mud, roots, rocks - Quick-release pins on the handle make it easy to position - The design allows for more leverage which reduces fatigue **Drawbacks** - Heavy - Expensive - Basket design may make it more difficult to immobilize head **http://www.fernorescue.com/products/basic-rescue/litter-wheels-stretcher-carriers/traverse-stretcher-carriers** **https://www.emrn.ca/en/mule-ii-litter-wheel-with-handles.html?fee=6&fep=2854**

Below are some pictures pulled from various sources to understand how stretcher systems are currently implemented. As can be seen, there have been exceptional advances in stretcher systems in recent years that have reduced the repeated physical loading of the paramedics. The implementation of a powered system that can work in both a land ambulance and a flight ambulance is a useful upgrade, allowing critical patients to be quickly transferred from one ambulance type to another.



Appendix D – Result Analysis

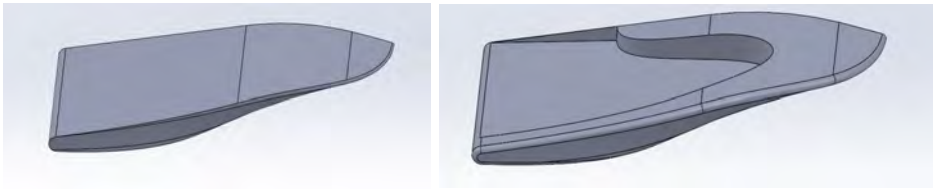
The following table is a tablulation of the benefits promoted by the brands of the existing products categorized in Appendix C. Each colomn moving right becomes more condensed and processed with the final column on the right summarizes findings.

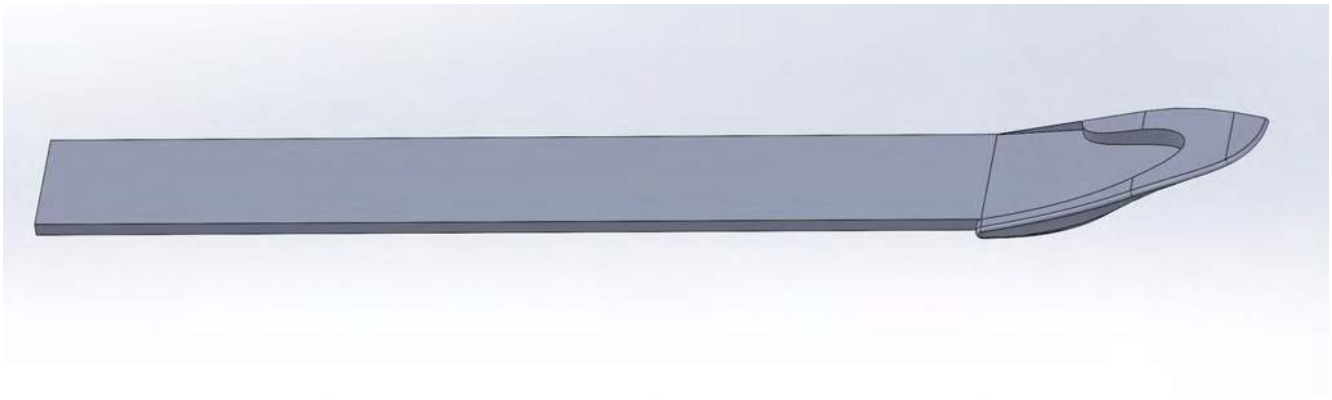


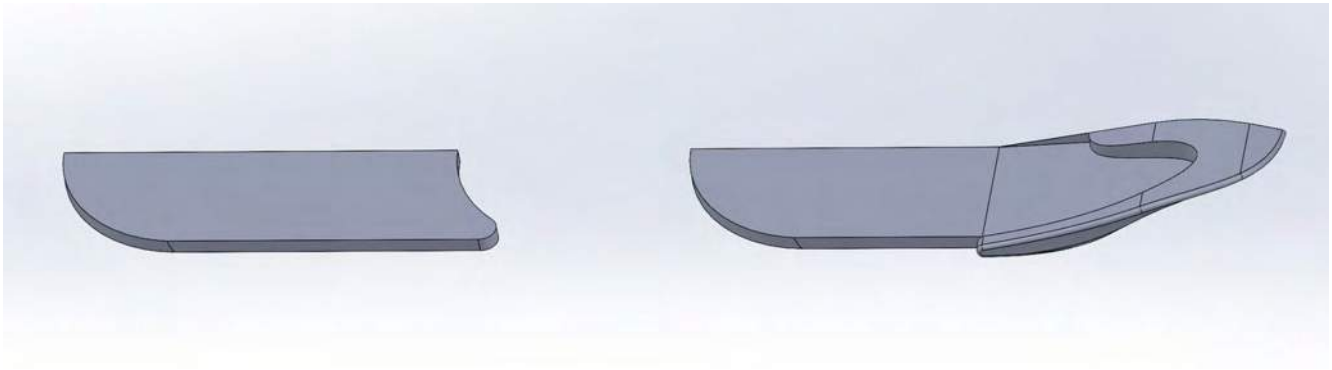
Raw Benefits Phrases	Clustering of Benefits	Categorization / Tally of Benefits			
accommodate all head shapes and injury positions	accommodate all head shapes and injury positions	Accommodating	5	Easy (to use)	14
accommodates all head types and injury positions.	accommodates all head types and injury positions.			Compatible	9
added protection against wear and tear.	compact storage and transport			Secure	8
aid in hypothermia prevention	Fits patients 2 years and up			Comfortable (for patient)	7
aid in hypothermia prevention	from 2 years, adults, children and infants, comfortably and securely			Cleanable	6
all purpose transport solution.	better communication and inspection	Inspectable (of Patient)	4	Durability	6
avoid second injury caused by disordered moving.	ensure visualization of the ears.			Accommodating	5
better communication and inspection.	functional access for the airway;			Inspectable (of Patient)	4
blocks will not float away!	having direct access to patients ears			Fast	4
can be attached to any style litter	Compact	Compact	3	Warming (prevent hypothermia)	4
comfort	compact size when not in use			Compact	3
comfort	Compact, easy storage			Lightweight	2
comfortable;	compatible with any type and style of rigid litter	Compatible	9		
Compact and lightweight	Compatible with most head immobilization devices				
compact size when not in use.	all purpose transport solution				
compact storage and transport	can be attached to any style litter				
Compact, easy storage	The base plate fits all Ferno backboards (except the NAJO Sports Board)				
compatible with any type and style of rigid litter	Universal				
Compatible with most head immobilization devices.	patient transportation by road, sea and air				
conform patient's forehead.	offers six (6) collars in one.				
durability and performance but at a disposable price; simple	Head supports can be used on standard backboards, or turned around for use on the				
ease of use;	easy to clean	Cleanable	6		
ease;	Easy to clean and decontaminate between uses				
easier access to the handholds	easy to clean and disinfect				
easily adjusted	easy to prevent bacterial growth				
easily adjusted	Will not absorb blood or bodily fluids				
easily and quickly operated.	no clean-up or lost equipment problems.				
easily operated in all weather conditions	durability and performance but at a disposable price; simple	Durability	6		
easy patient transfer.	reusable base and blocks resistant to punctures and tears				
easy steps	improved rigidity and durability;				
easy to clean	added protection against wear and tear				
Easy to clean and decontaminate between uses	heavy-duty				
easy to clean and disinfect	ideal for narrow trails, allows for agility, versatility and ease of movement in the roughest terrain				
easy to operate with heavy gloves on.	ease;	Easy (to use)	14		
easy to prevent bacterial growth	easily adjusted				
easy;	easier access to the handholds;				
enhances patient comfort	easily and quickly operated.				
ensure that the victim's body is secured safely;	easily operated in all weather conditions				
ensure visualization of the ears.	easy patient transfer.				
exceptional water rescue properties;	simple to use,				
Fast	ease of use;				
Fits patients 2 years and up.	easy steps;				
from 2 years, adults, children and infants, comfortably and securely	easy to operate with heavy gloves on.				
functional access for the airway;	easily adjusted				
having direct access to patients ears	easy.				
Head supports can be used on standard backboards, or turned around	releasing easily during removal				
heavy-duty	reduces fatigue and the chance of injury				
ideal for narrow trails, allows for agility, versatility and ease of movement	Fast	Fast	4		
immobilized in a matter of minutes	immobilized in a matter of minutes				
improved rigidity and durability;	rapidly and safely adjust				
isolative and cold-resisting	quick.				

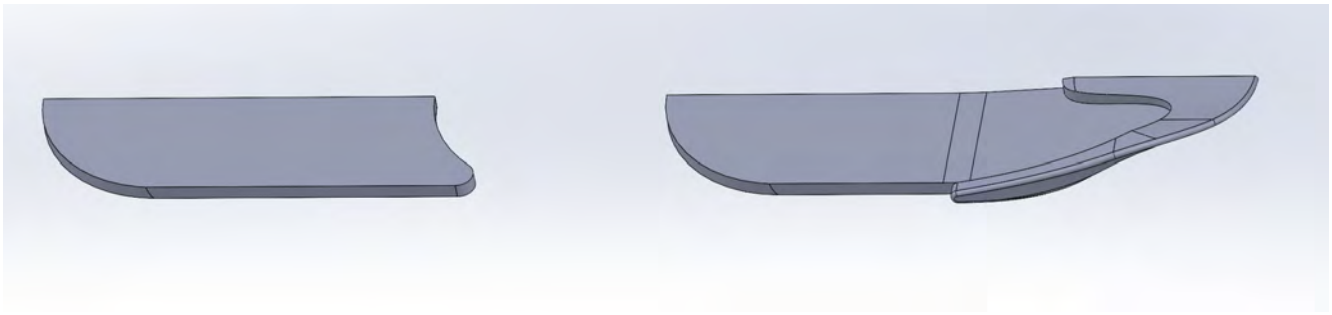
light weight	hypothermia prevention	Warming (prevent hypothermia)		
Lightweight,	isolative and cold-resisting			
little risk of moving head.	aid in hypothermia prevention	4		
lock patients securely into place, regardless of the head shape or posit	aid in hypothermia prevention			
maximum motion restriction	light weight	Lightweight		
no clean-up or lost equipment problems.	Lightweight,	2		
offers greater tracking ability and shock absorption for smooth and co	maximum motion restriction	Secure		
offers six (6) collars in one.	ensure that the victim's body is secured safely.			
patient transportation by road, sea and air.	will not sway over obstacles or uneven ground			
quick,	secure the head ensuring patient stabilization.			
rapidly and safely adjust;	lock patients securely into place, regardless of the head shape or position.			
reduces fatigue and the chance of injury.	little risk of moving head.	8		
releasing easily during removal	ensure that the victim's body is secured safely.			
reusable base and blocks resistant to punctures and tears	avoid second injury caused by disordered moving			
secure the head ensuring patient stabilization.	patient comfort	Comfortable (for patient)		
simple to use,	comfort			
simple to use.	offers greater tracking ability and shock absorption for smooth and comfortable patient transport			
suitable for adult, child and infants.	enhances patient comfort			
The base plate fits all Ferno backboards (except the NAJO Sports Boar	conform patient's forehead	7		
Universal	comfortable,			
used by many aquatic facilities	wick away moisture to ensure proper patient hygiene and comfort while preventing skin irritation			
wick away moisture to ensure proper patient hygiene and comfort while preventing skin irritation				
Will not absorb blood or bodily fluids				
will not sway over obstacles or uneven ground				

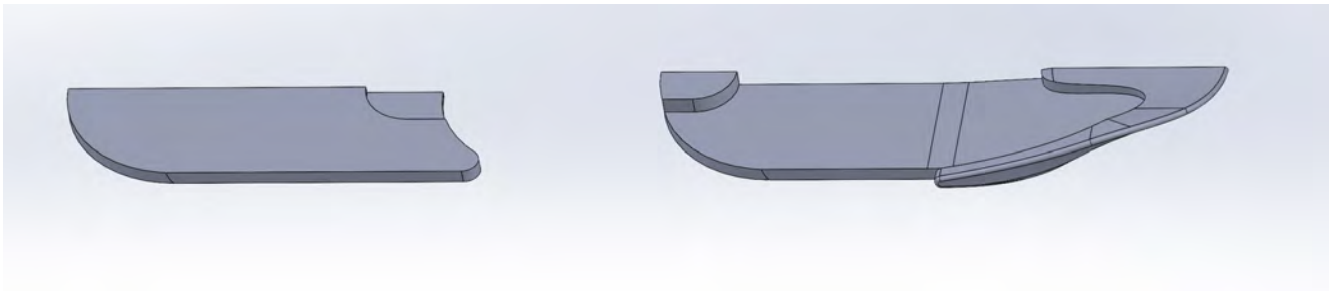
Appendix E – CAD Development

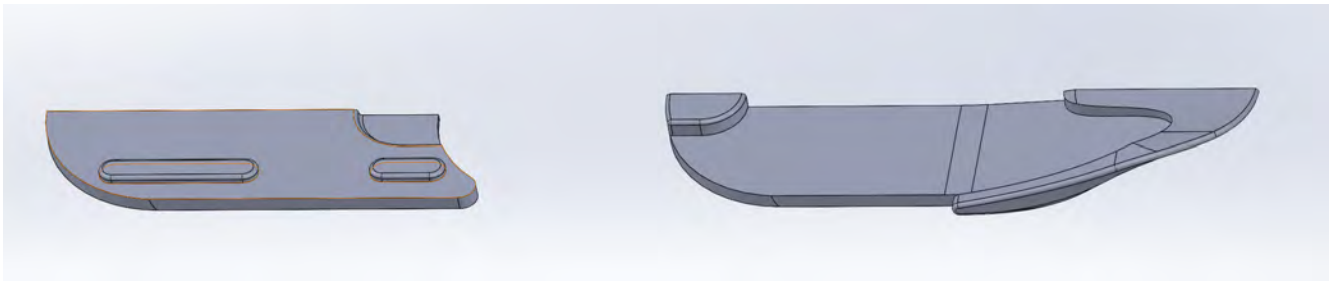


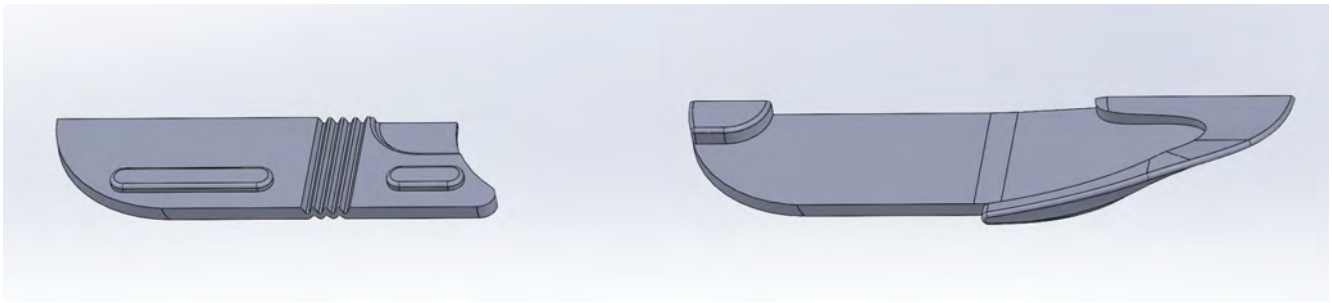


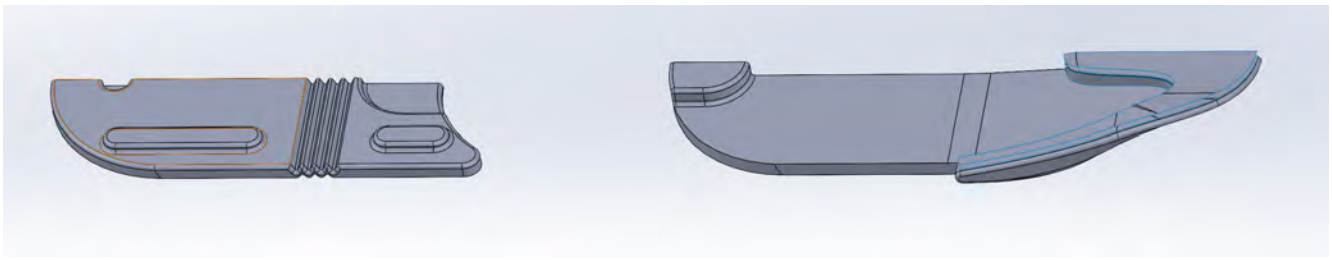


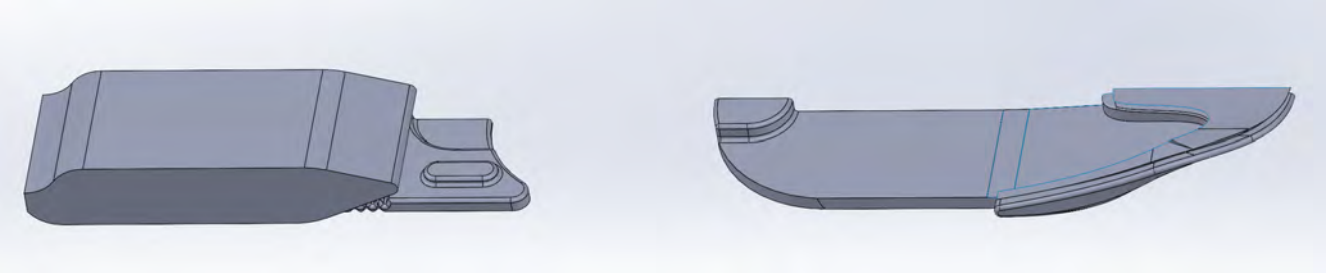


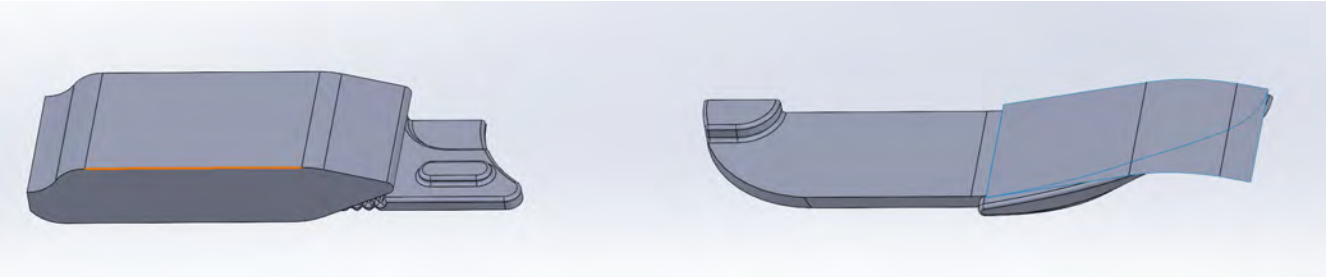


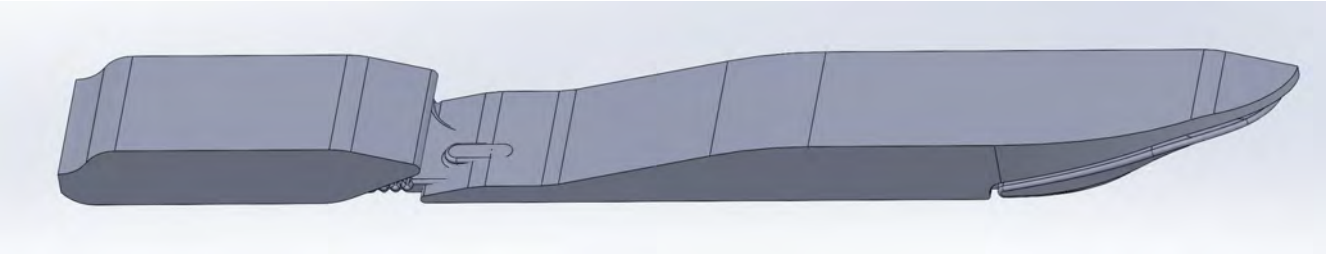


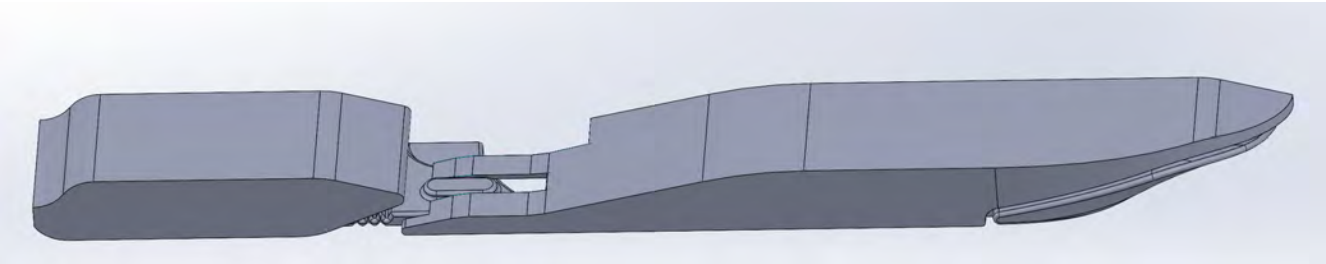


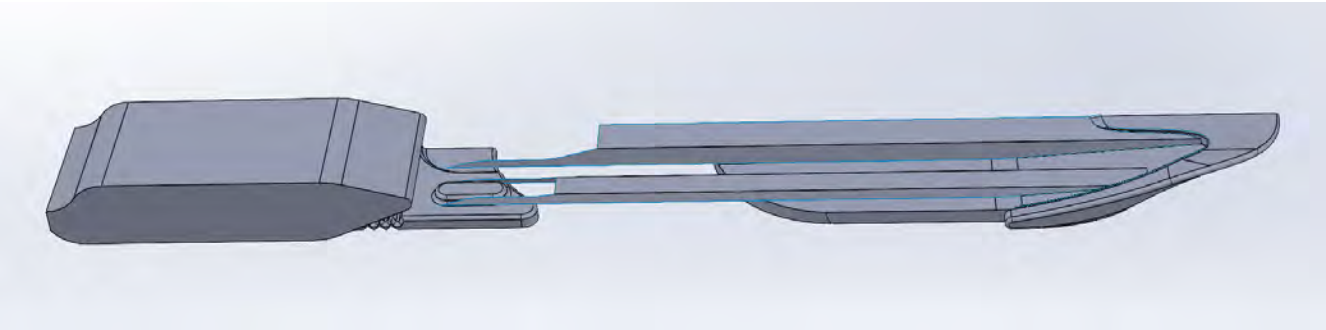


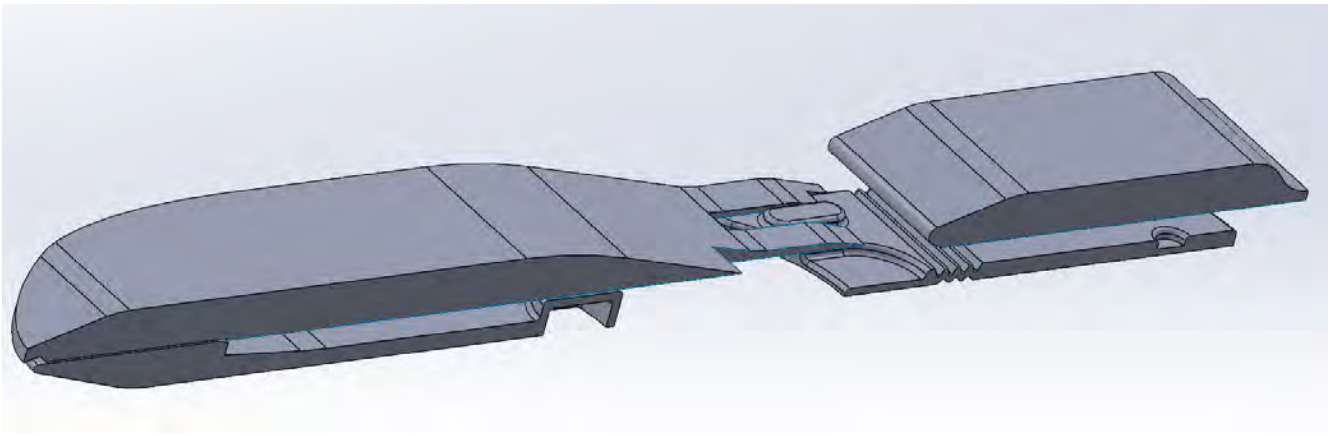


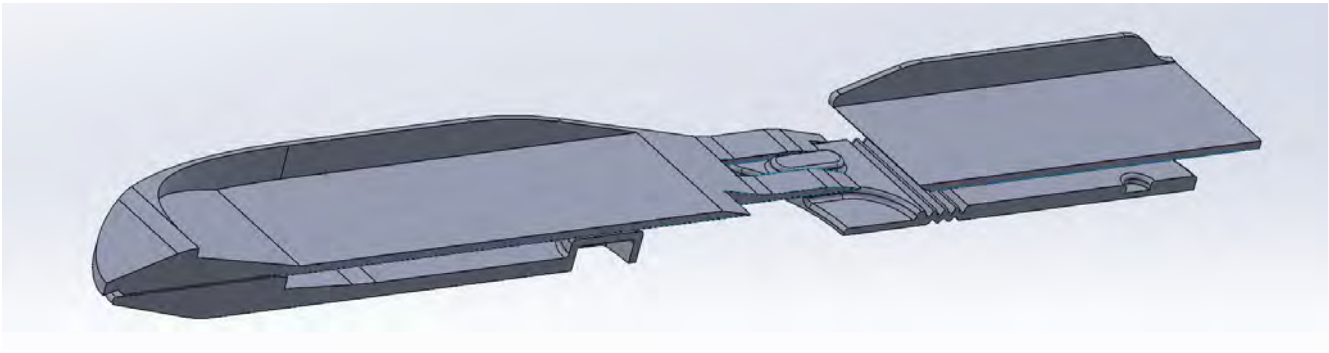


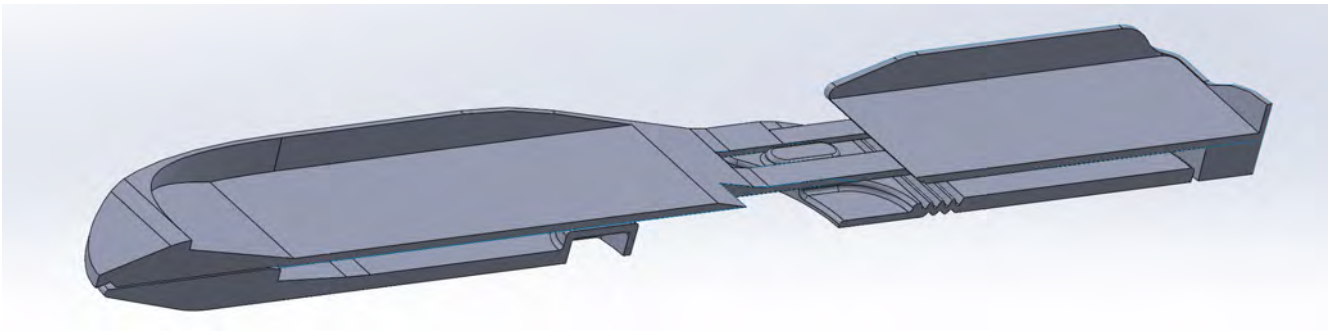


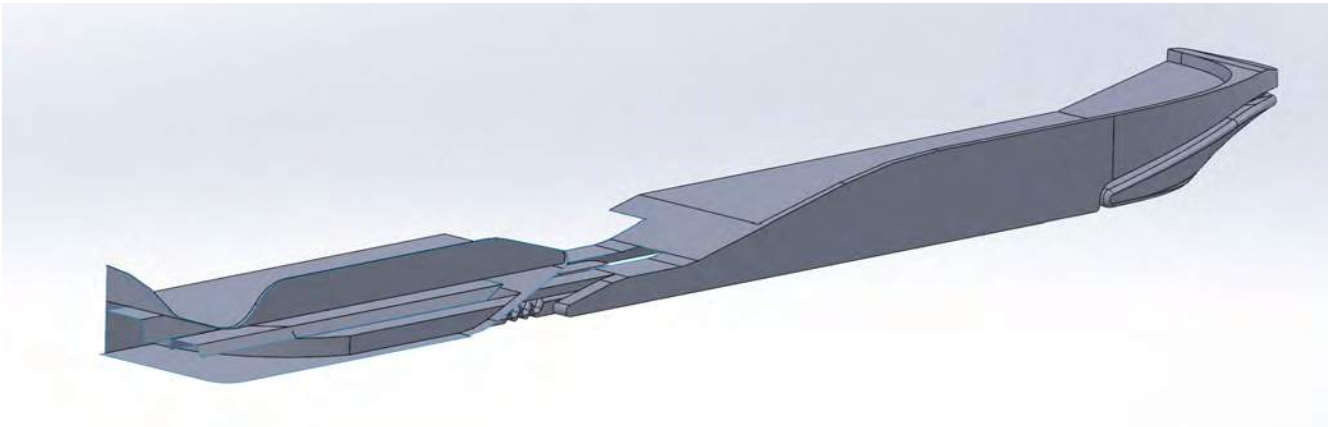


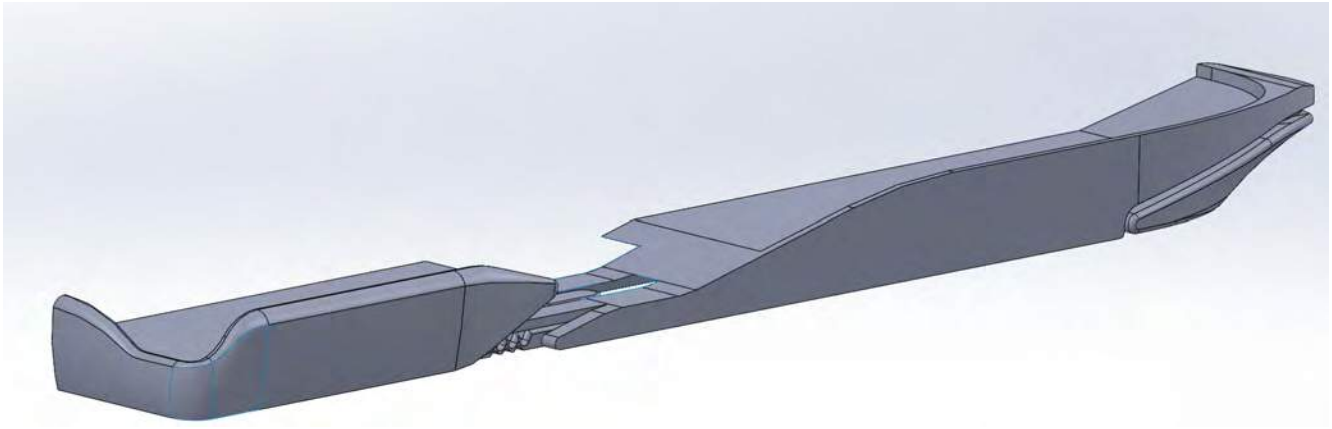


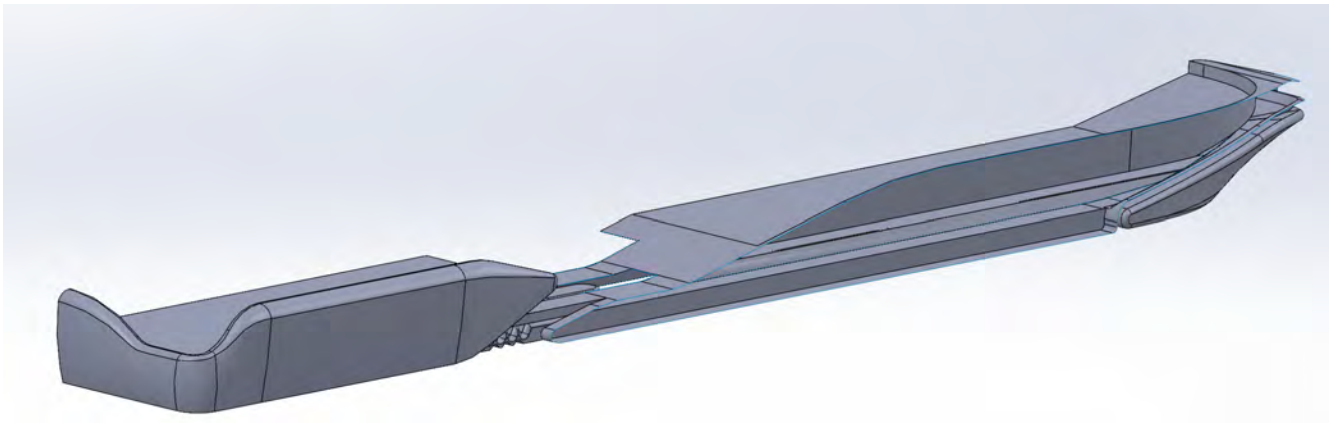


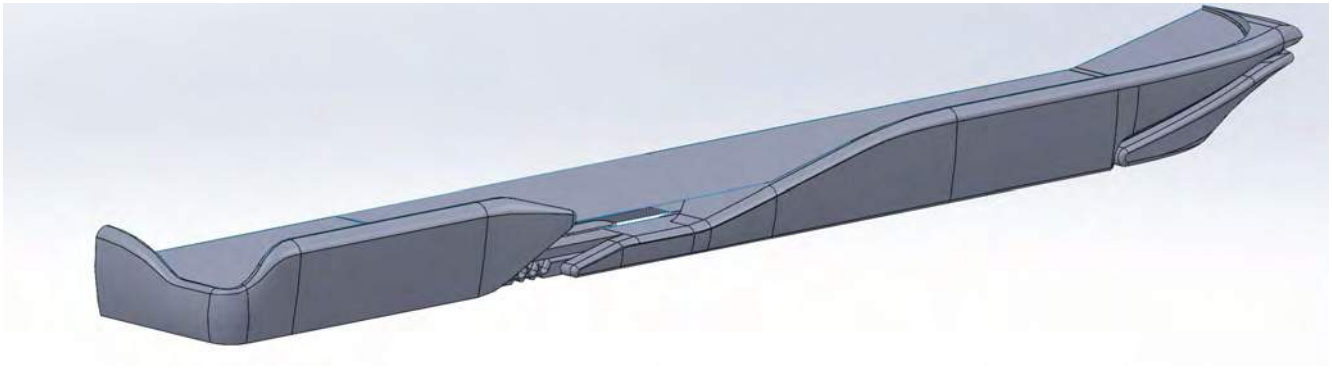


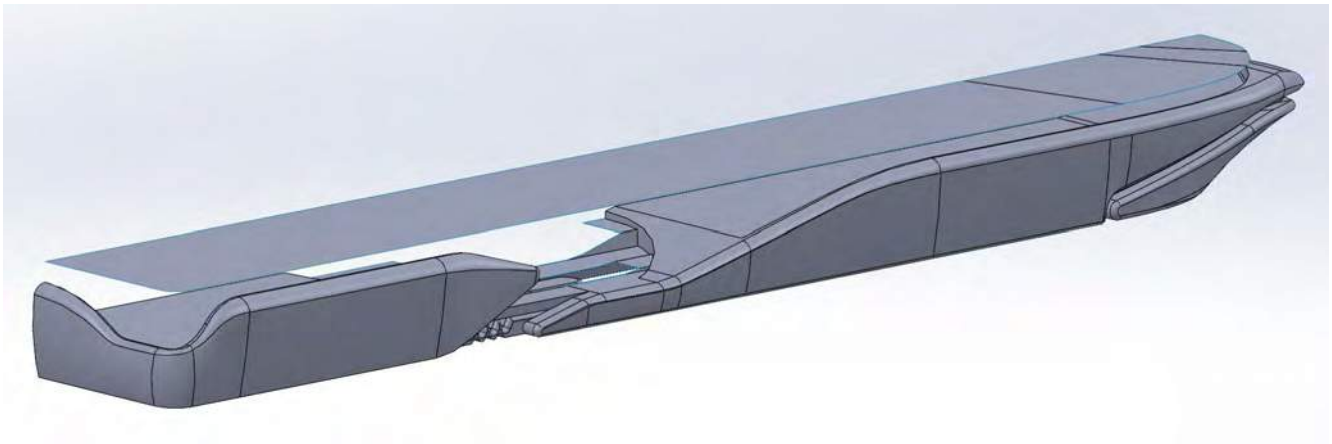


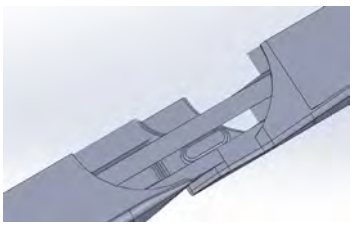
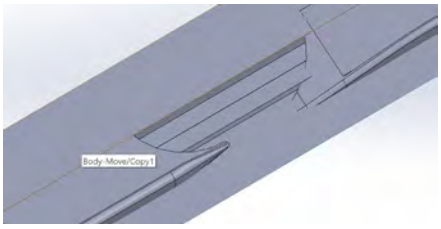








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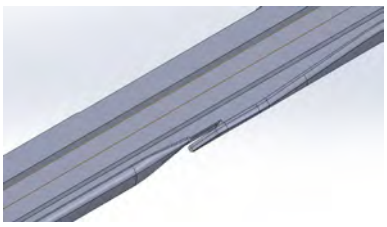
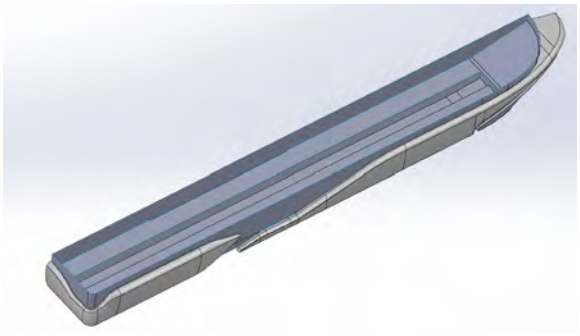
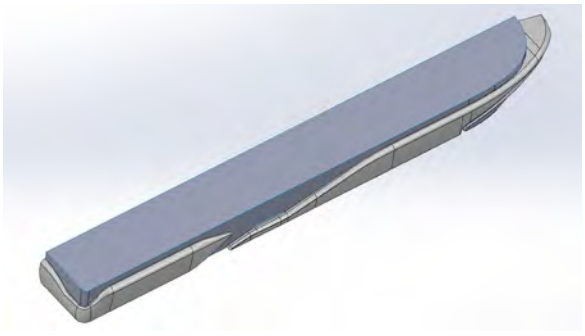
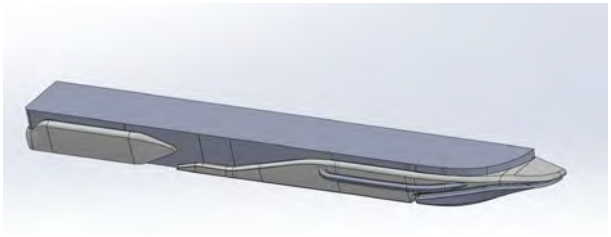
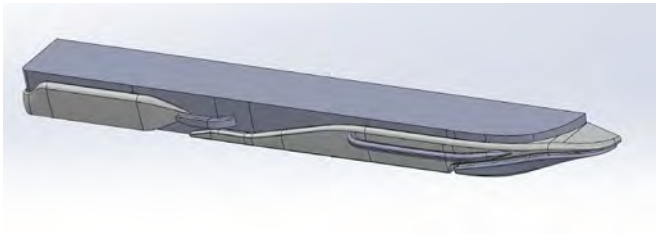
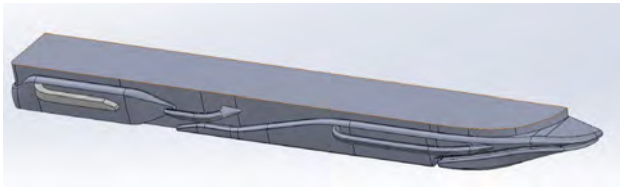
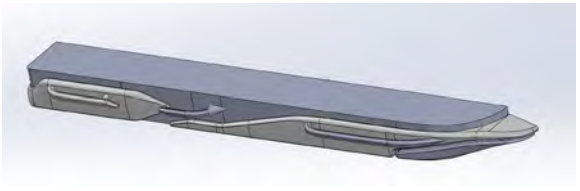
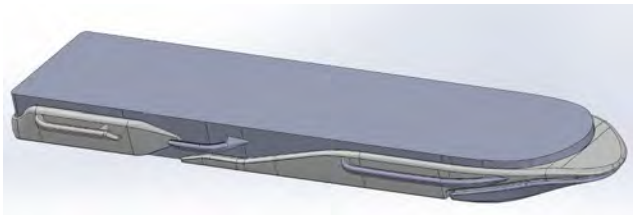
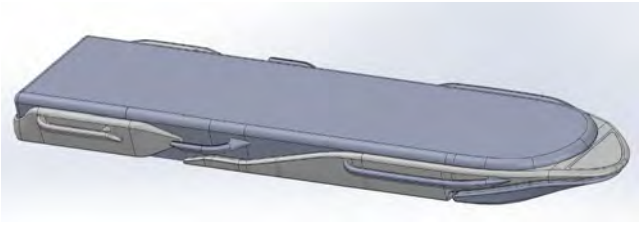
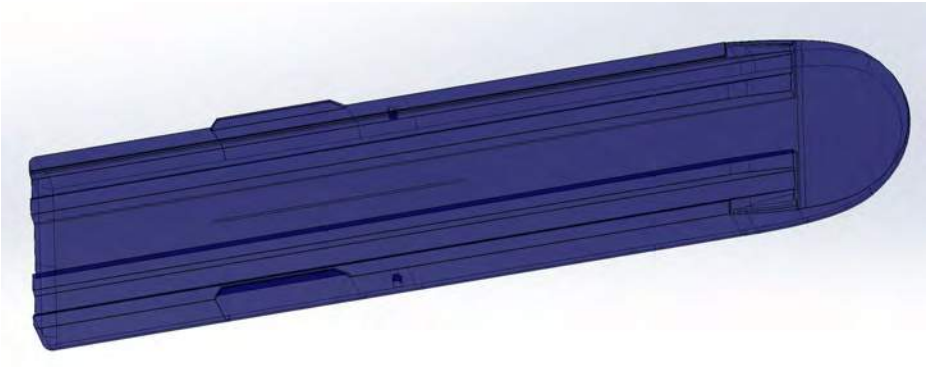
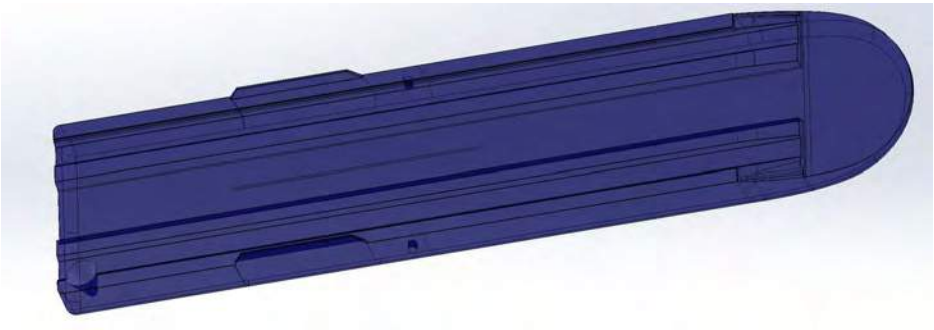
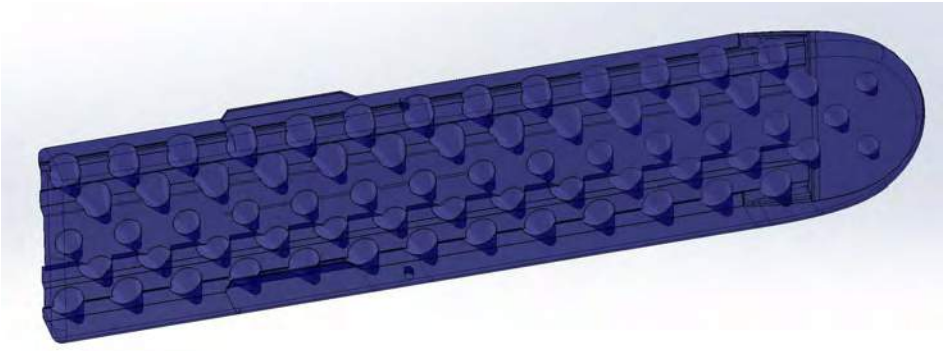
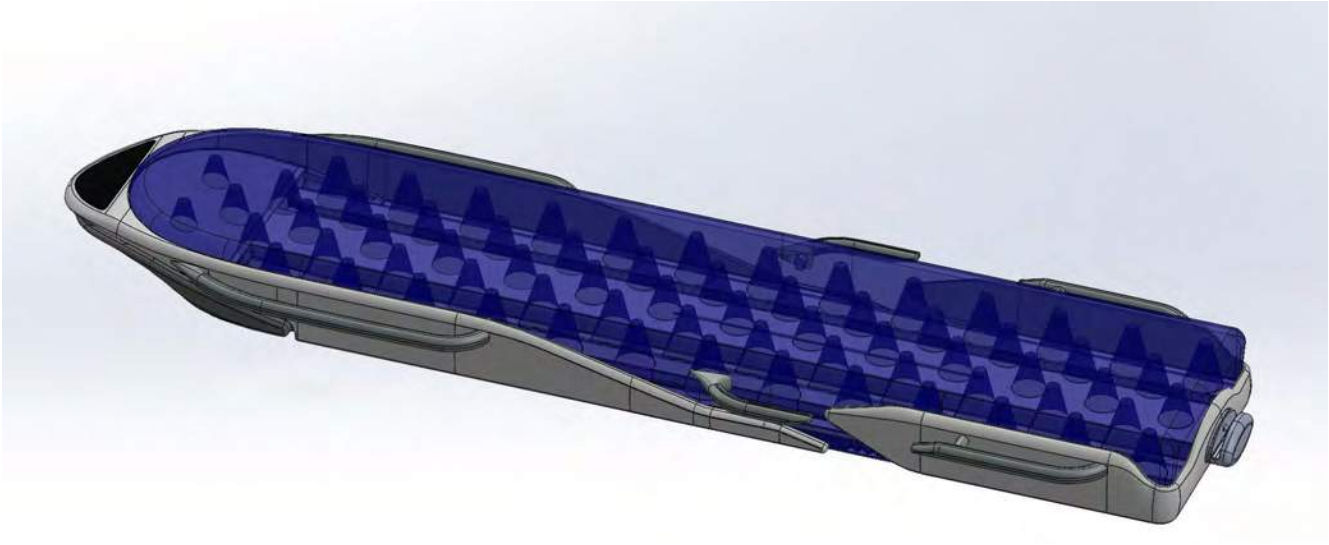










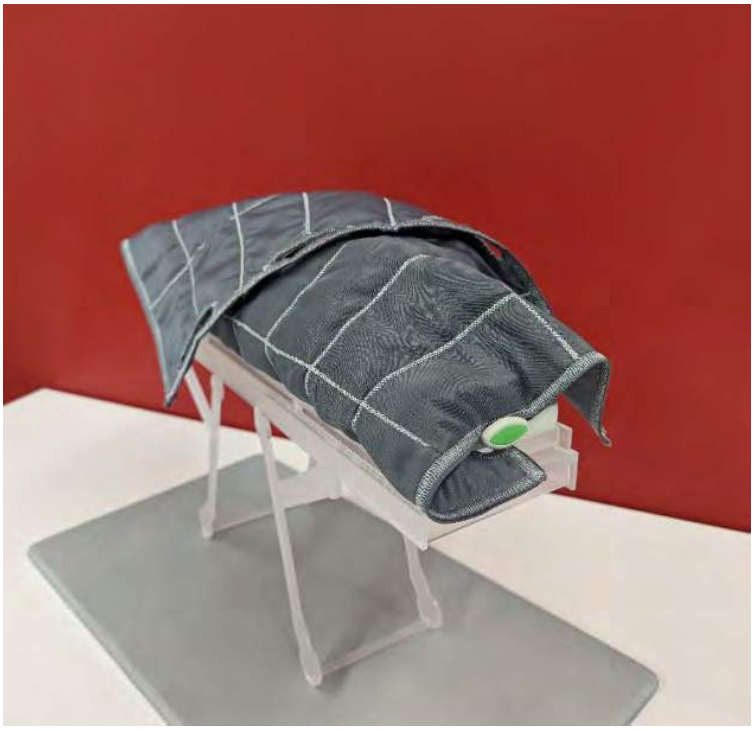


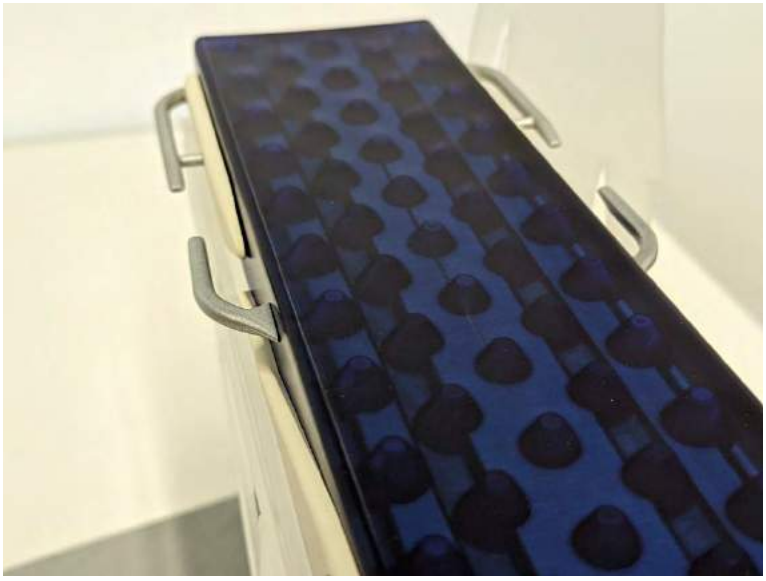


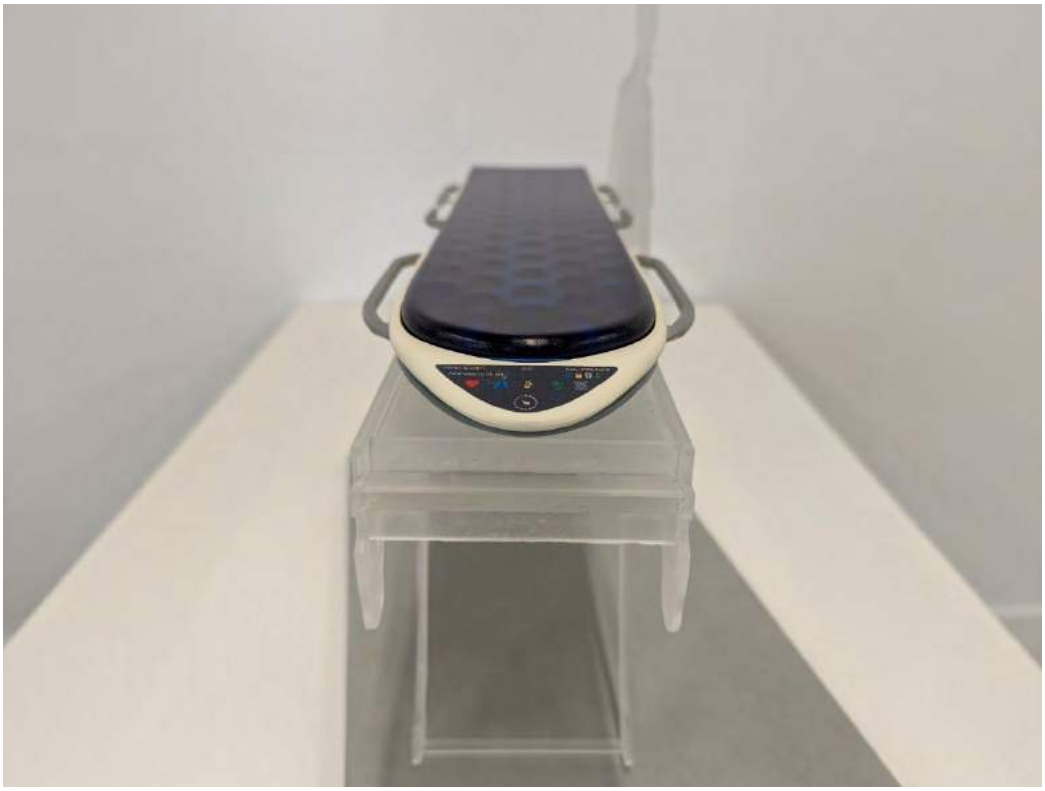


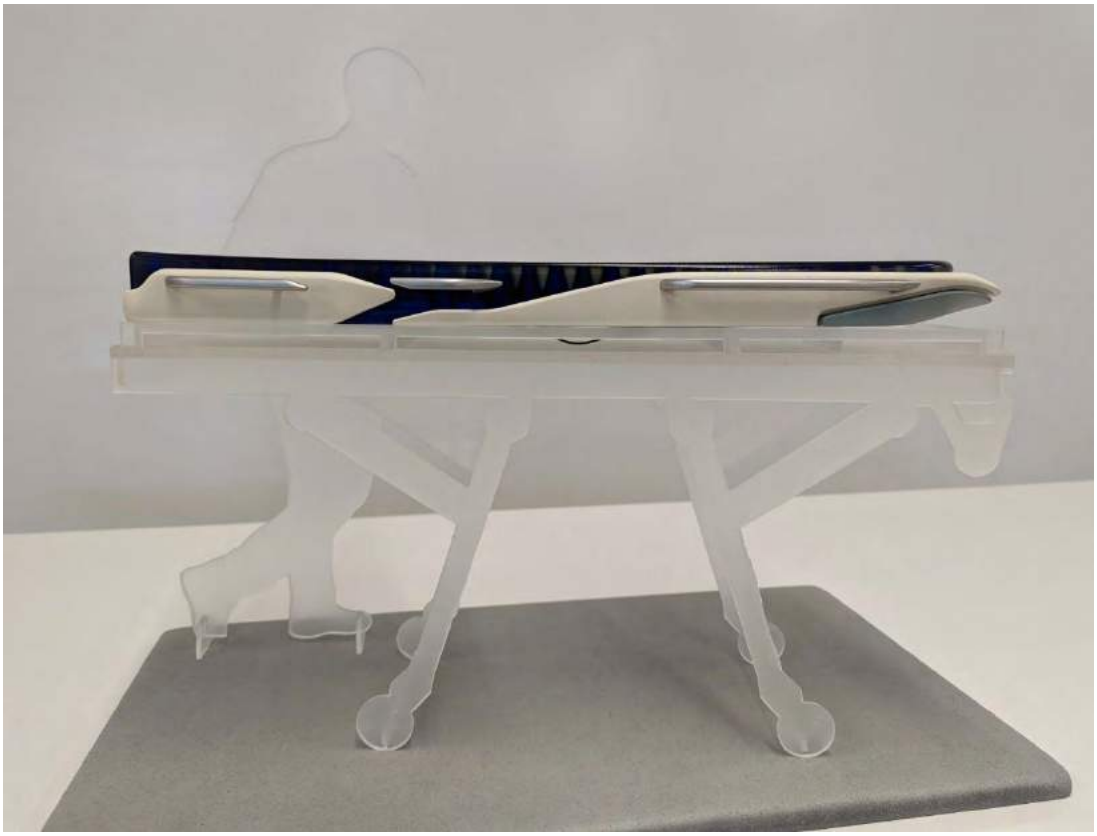


Appendix F – Physical Model Photographs

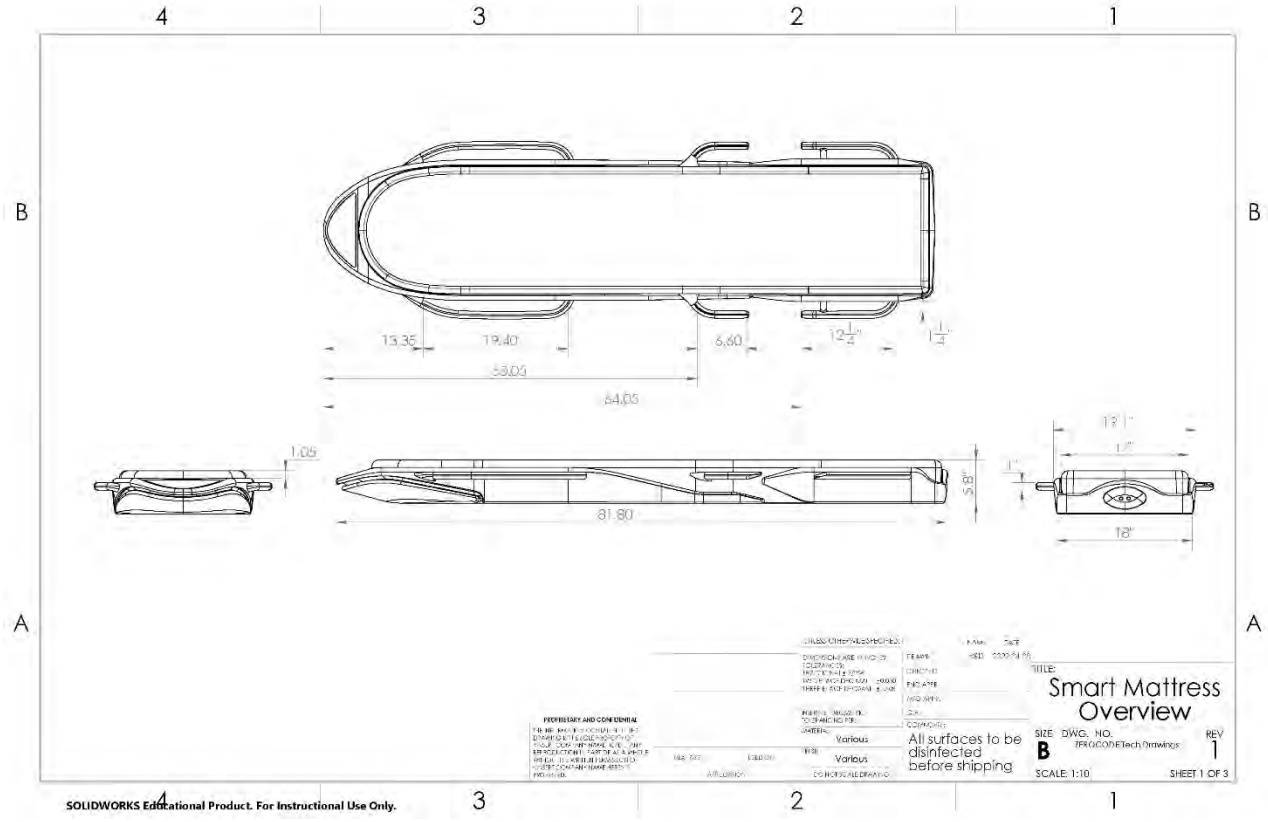


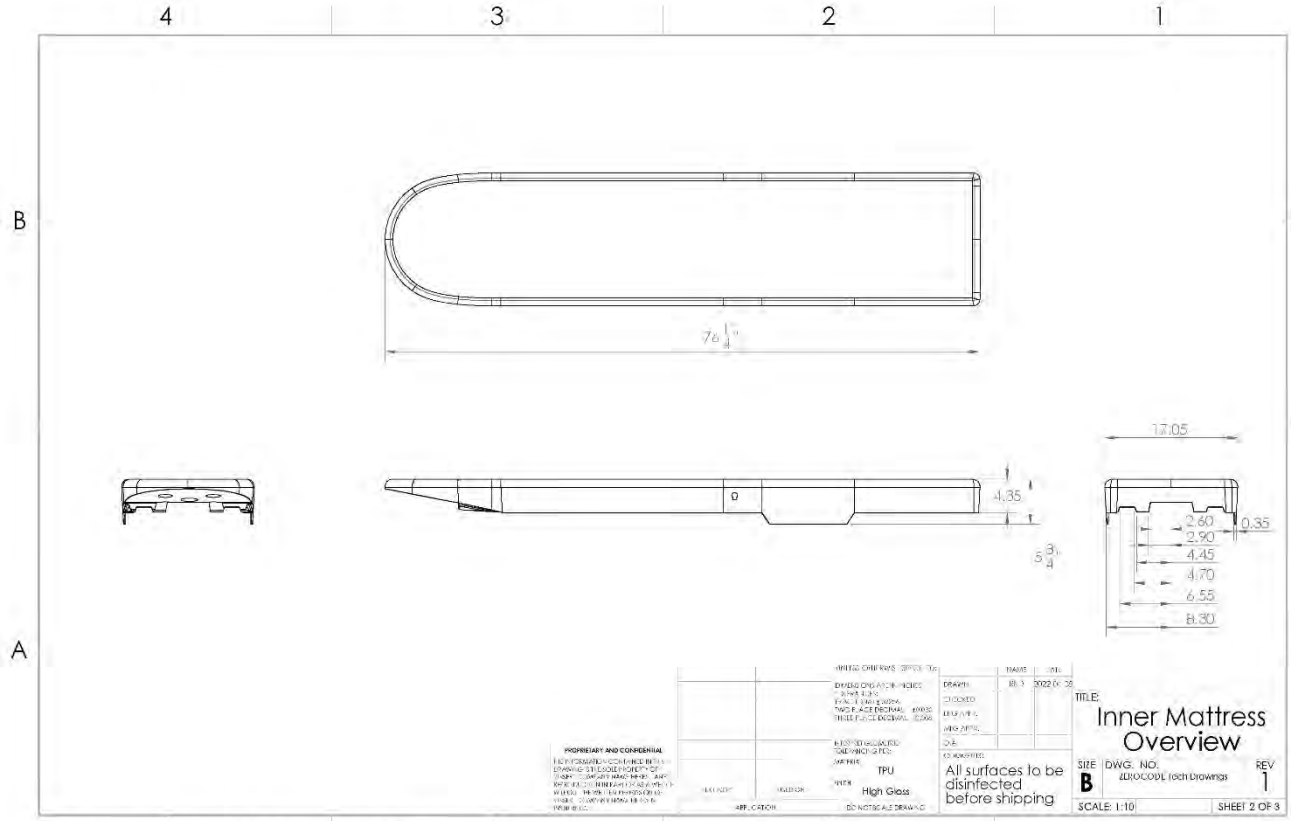




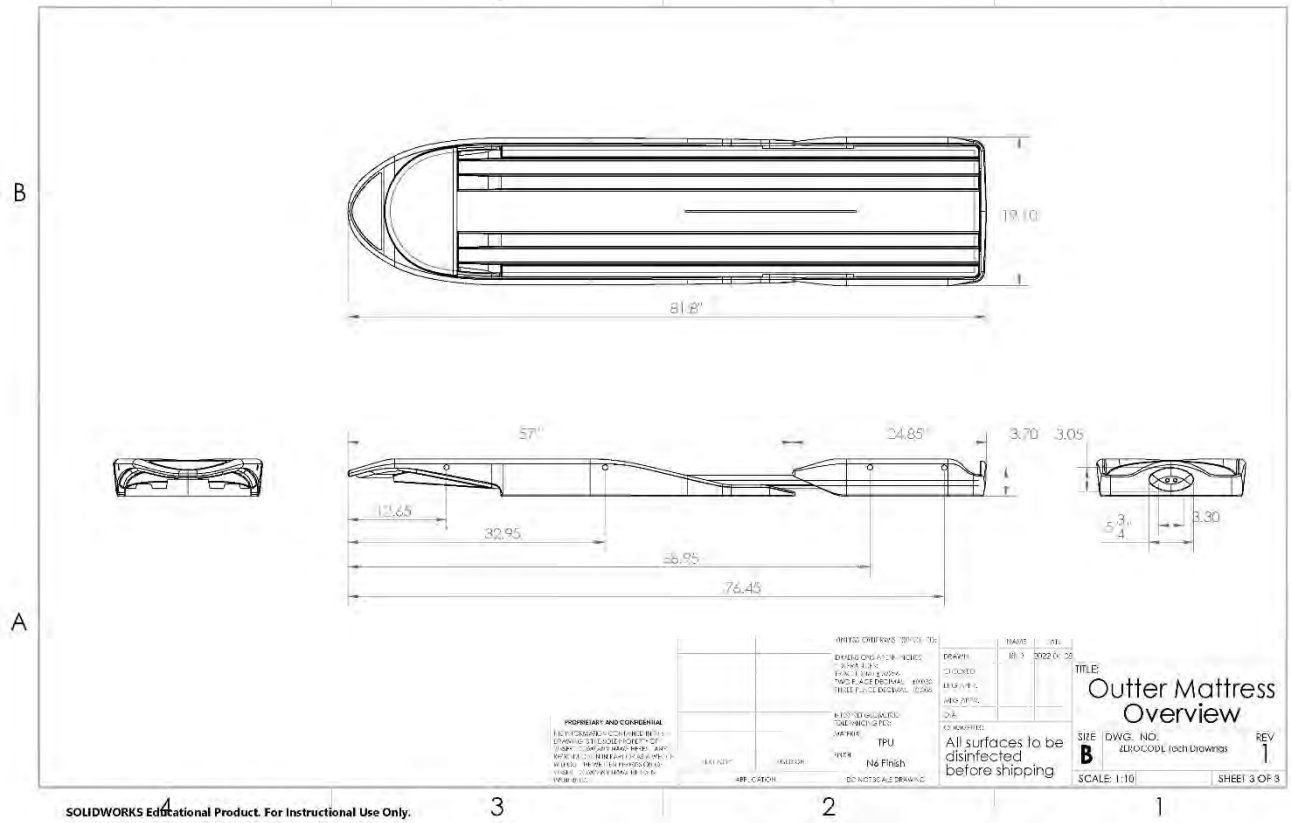


Appendix G – Technical Drawings





SOLIDWORKS Educational Product. For Instructional Use Only.



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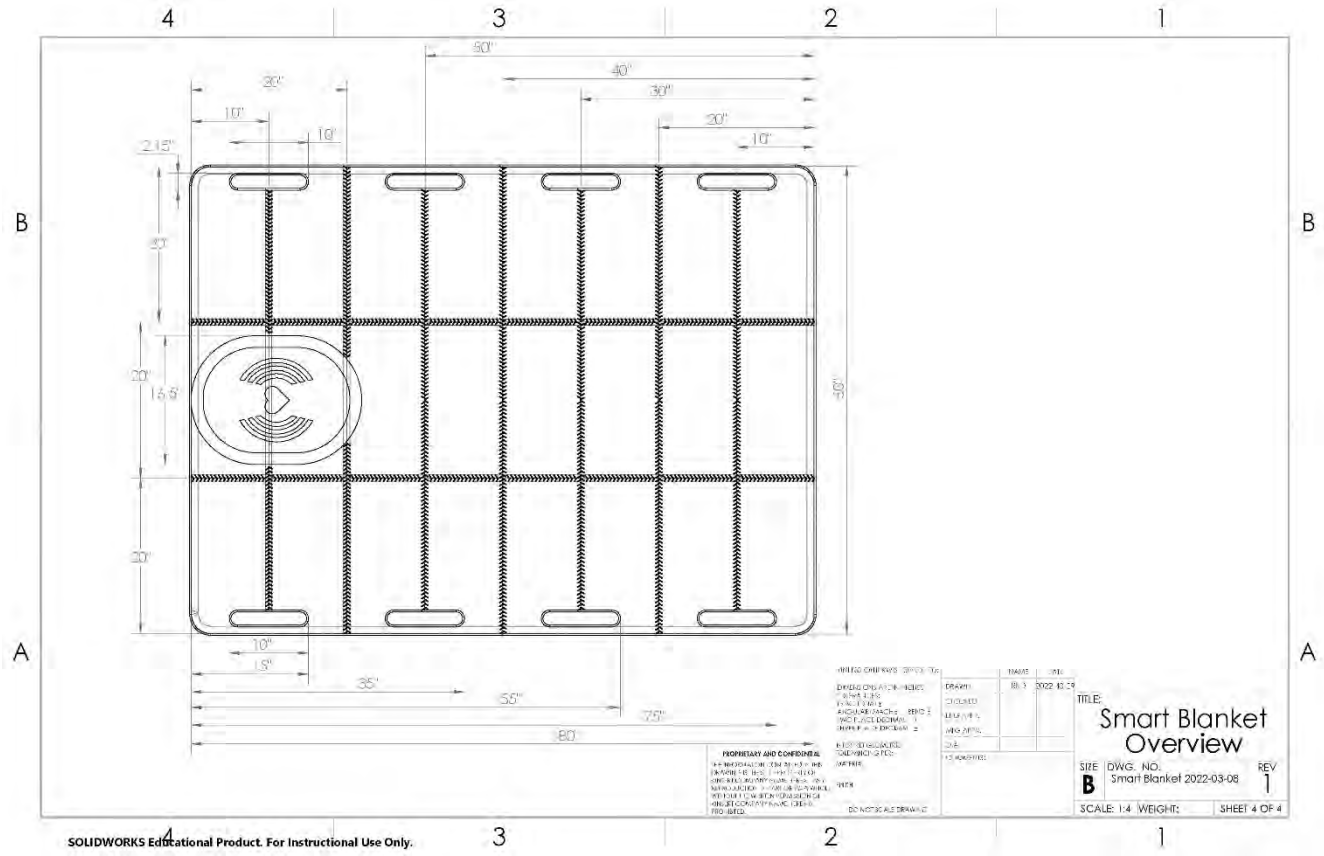
50"
40"
30"
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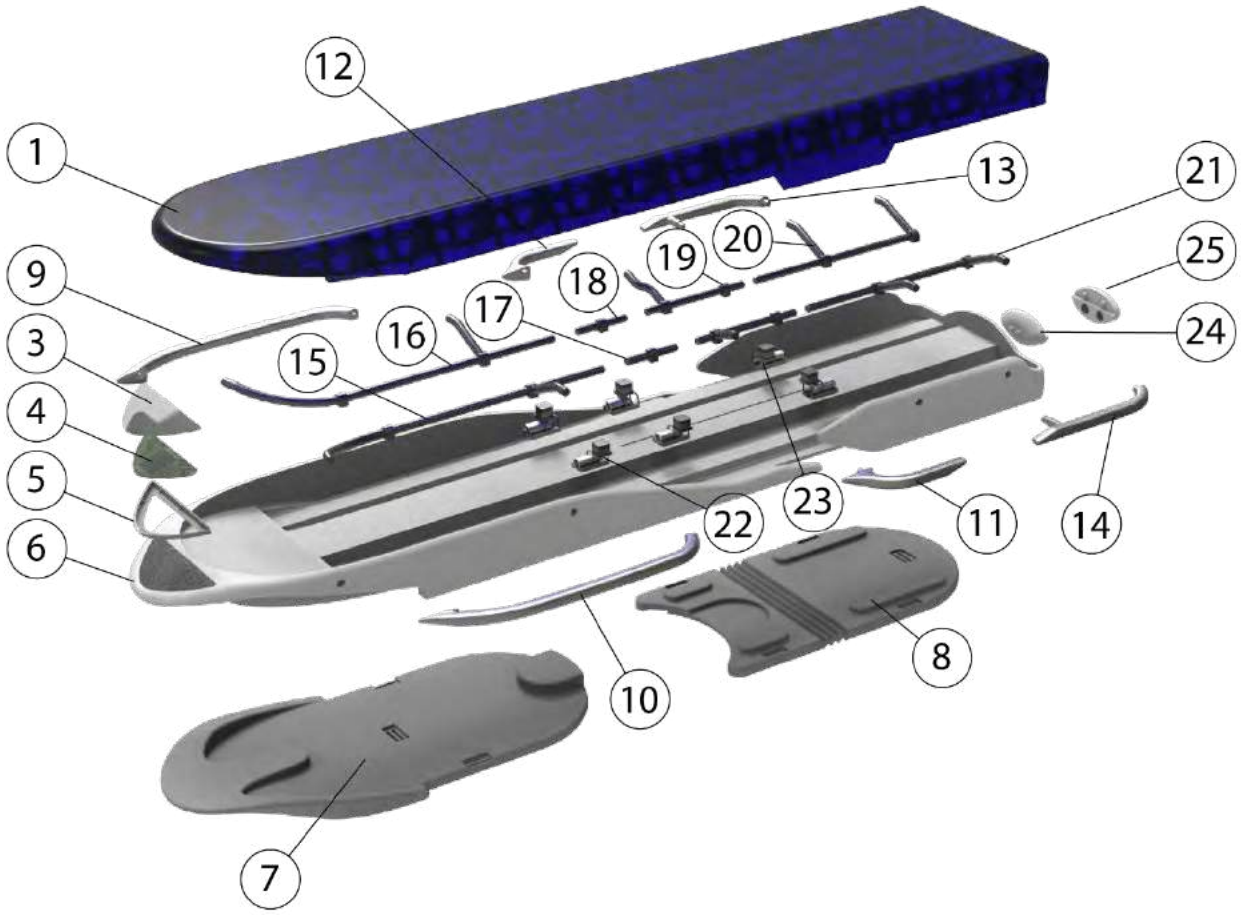
10"
2.15"
40"
20"
16.6"
20"
50"
10"
15"
35"
55"
75"
80"
Smart Blanket Overview
SIZE B
DWG. NO. Smart Blanket 2022-03-08
REV 1
SCALE: 1:4 WEIGHT:
SHEET 4 OF 4
PROPRIETARY AND CONFIDENTIAL
SOLIDWORKS Educational Product. For Instructional Use Only.

Appendix H – Bill of Materials Info/Data

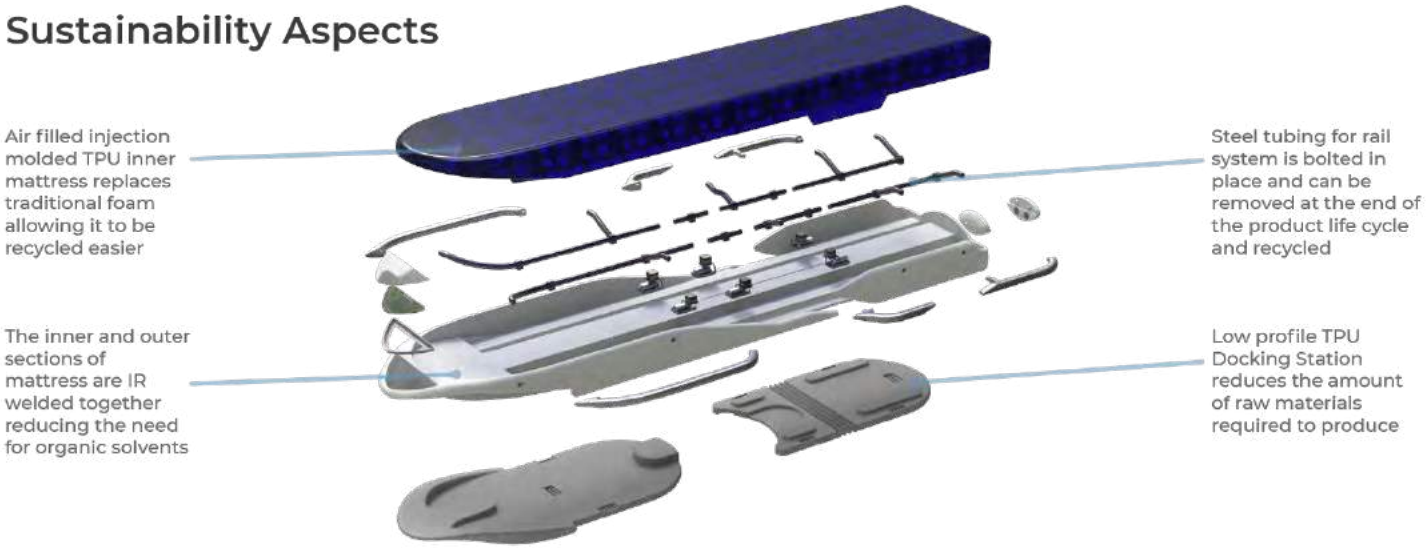


Part #	Description	Quantitiy	Material	Manufacturing Method	Price
1	Inner Mattress	1	Thermoplastic Polyurethane	Injection Molding	$3,500.00
2	Webbing - Connector Strapping	2	Nylon	Woven	$10.50
3	Screen Cover	1	Polycarbonate	Injection Molding	$10.00
4	Printed Circuit Board	1	FR-4/Copper	Prepreg Fibre Glass/Pick and Place	$10.00
5	Screen Mount	1	Polypropylene	Injection Molding	$10.00
6	Outer Mattress	1	Thermoplastic Polyurethane	Injection Molding	$2,800.00
7	Front Piece of Docking Station	1	High Derometer Thermoplastic Polyurethane	Blow Moulding	$1,785.00
8	Rear Piece of Docking Station	1	High Derometer Thermoplastic Polyurethane	Blow Moulding	$1,785.00
9	Left Front Handle	1	Brushed Steel	Steel Hydroforming	$225.00
10	Right Front Handle	1	Brushed Steel	Steel Hydroforming	$225.00
11	Right Center Handle	1	Brushed Steel	Steel Hydroforming	$225.00
12	Left Center Handle	1	Brushed Steel	Steel Hydroforming	$225.00
13	Left Rear Handle	1	Brushed Steel	Steel Hydroforming	$225.00
14	Right Rear Handle	1	Brushed Steel	Steel Hydroforming	$225.00

15	Right Front Coupling Rod Assembly	1	Aluminum Tubing	Aluminum Extrusion	$62.00
16	Left Front Coupling Rod Assembly	1	Aluminum Tubing	Aluminum Extrusion	$62.00
17	Right Forward Center Rod Assembly	1	Aluminum Tubing	Aluminum Extrusion	$24.00
18	Left Forward Center Rod Assembly	1	Aluminum Tubing	Aluminum Extrusion	$24.00
19	Left and Right Rear Center Rod Assembly	1	Aluminum Tubing	Aluminum Extrusion	$50.00
20	Rear Coupling Rod Assembly	1	Aluminum Tubing	Aluminum Extrusion	$110.00
21	Left Coupling Rod Assembly	1	Aluminum Tubing	Aluminum Extrusion	$110.00
22	Right Coupling Motor Assembly	1	Aluminum /Steel	Aluminum Extrusion	$65.00
23	Left Coupling Motor Assembly	1	Aluminum /Steel	Aluminum Extrusion	$45.00
24	Backing Plate of Smart Blanket Connector	1	High Derometer Thermoplastic Polyurethane	Injection Molding	$62.00
25	Front Plate of Smart Blanket Connector	1	High Derometer Thermoplastic Polyurethane	Injection Molding	$62.00
26	Smart Blanket PLA Polyester Fabric	1	PLA Polyester Fabric	Woven	$200.00
27	Thermal Sensors Thread	1	High Derometer Thermoplastic Polyurethane	Injection Molding	$300.00
29	ECG Wireless Device	1	Various Materials	Assembled	$1,200.00
					$13,636.50

Appendix I – Sustainability Info/Data

Sustainability Aspects



Appendix J – Approval Forms & Plans

IDSN 4002
SENIOR LEVEL THESIS ONE

Humber ITAL / Faculty of Applied Sciences & Technology
Bachelor of Industrial Design / FALL 2021
Catherine Chong / Sandro Zaccolo

THESIS TOPIC APPROVAL:

Student Name:	Raymond Daniel
Topic Title:	How may we improve the transportation of critical care patients to be more effective?

TOPIC DESCRIPTIVE SUMMARY (Preliminary Abstract)

A critical care paramedic transports a patient between two hospitals or from the scene of an accident to a hospital. Critical care paramedics often provide medical intervention to patients at risk of an imminently worsening condition due to an illness or injury (Association of Critical Care Transport, 2016). While critical care paramedics do have access to many effective and advanced technologies, some tools are outdated and have been shown, in recent years, to be ineffective and cause secondary injuries (Kane & Braithwaite, 2021). Therefore, how may we improve the transportation of critical care patients to be more effective? Tools such as the long spine board have been the standard for transporting patients in critical condition since the 1960s (Kane & Braithwaite, 2021). In recent years, research has shown that long spine boards (LSB) may not be the best tool to immobilize a patient's spine. For instance, in trauma patients with penetrating wounds, spinal immobilization has been shown to increase the chances of mortality (Haut et al., 2010). This thesis project will use various research methods to understand the needs of both critical care paramedics and their patients. Information will be gained through sources such as interviews, user observational studies, and surveys. Sources for primary research will originate from existing contacts in the first-responder industry with the intent to meet new sources through secondary connections. Additionally, preliminary research will be directed and fortified by secondary research methods such as literary reviews. The information gathered from this investigation has the potential to help not only paramedics but also all who use their services. Driven by the data collected, an evidence-based solution will be tested through sketch models and a full-size mock-up to evaluate the design's ergonomics. The final solution will potentially allow critical care paramedics to save lives more effectively.

Student Signature(s):	Ray Daniel
Date:	October, 6, 2021

Instructor Signature(s):	Catherine Chong Sandro Zaccolo
Date:	07 October 2021

PANEL ON RESEARCH ETHICS
Navigating the ethics of human research

TCPS 2: CORE

Certificate of Completion

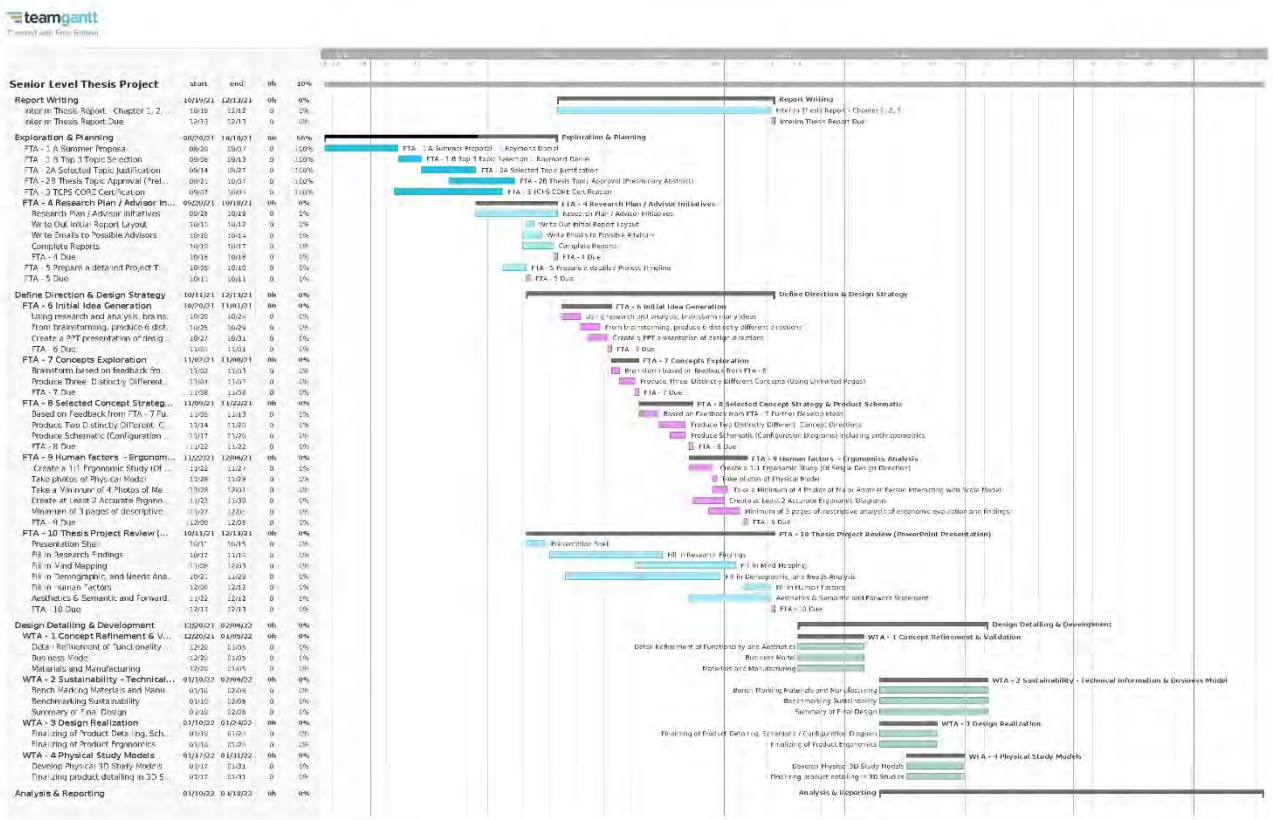
This document certifies that

Raymond Daniel

has completed the Tri-Council Policy Statement:
Ethical Conduct for Research Involving Humans
Course on Research Ethics (TCPS 2: CORE)

N01230562

Date of Issue: **28 September, 2021**



Appendix K – Advisor Meetings & Agreement Forms

HUMBER
Faculty of Applied Sciences & Technology
Bachelor of Industrial Design / FALL 2021 & WINTER 2022

IDSN 4002 / 4502
SENIOR LEVEL THESIS ONE & THESIS TWO

INFORMATION LETTER

Research Study Topic:	How may we improve the transportation of critical care patients to be more effective?
Investigator:	Raymond Daniel / 250-217-6367 / raykdaniel@gmail.com
Sponsor:	Humber ITAL, Faculty of Applied Sciences & Technology (IDSN 4002 & IDSN 4502)

Introduction
My name is Raymond Daniel, I am an industrial design student at Humber ITAL, and I am inviting your participation in a research study on various problems that critical care paramedics encounter. These problems deal with the efficiency of patient transport, ergonomic hazards of duty, and comfort of patients. The results will be contributed to my Senior Level Thesis project.

Purpose of the Study
This study is being conducted as an aid in designing a tool for paramedics that is capable of increasing the efficiency of transporting critically ill patients. The product to be designed is inspired by the existing head and spinal immobilization devices on the market and other medical devices. Your input will provide real-world context and industry experience to help focus on problems that require solutions the most. This study is primarily based on understanding ergonomics, human interaction design activities, and user experience aspects of the research area.

Procedures
If you volunteer to participate in this study, any interviews, and/or user observation studies will be observed and recorded/documented. Further elaborating, during interviews and/or user observation studies, your activities will be documented via video recording, audio recording and/or written notes.

Confidentiality
Every effort will be made to ensure confidentiality of any identifying information that is obtained during the study. In the case of being recorded visually, your face will be masked /blurred or hidden. The information and documentations (photographs) gathered are all subject to being used in the final presentation of the study.

Participation and Withdrawal
Your participation in this study is completely voluntary and you may interrupt or end the study and the session at any time without giving a reason or fear of being penalized.

If at any point during the session, you feel uncomfortable and wish to end your participation, please let the moderator know and they will end your participation immediately.

Humber Research Ethics Board
This research project /course has been approved by the Humber Research Ethics Board. If you have any questions about your rights as a research participant, please contact Dr. Lydia Boyko, REB Chair, 416-675-6622 ext. 79322, **Lydia.Boyko@humber.ca**

IDSN 4002 / 4502
SENIOR LEVEL THESIS ONE & THESIS TWO

HUMBER
Faculty of Applied Sciences & Technology
Bachelor of Industrial Design / FALL 2021 & WINTER 2022

INFORMATION LETTER

Conditions of Participation

- ✓ I understand that I am free to withdraw from the study at any time without any consequences.
- ✓ I understand that my participation in this study is confidential. (i.e. the researcher will know but will not disclose my identity)
- ✓ My identity will be masked.
- ✓ I understand that the data from this study may be published.

☑ **I have read the information presented above and I understand this agreement. I voluntarily agree to take part in this study.**

Barrie Martin	*Barrie Martin*	October 13 2021
Participant's Name	Participant's Signature	Date

Project Information

Thank you very much for your time and help in making this study possible. If you have any queries or wish to know more about this Senior Level Thesis project, please contact me at the followings:

Phone: 250-217-6367

Email: raykdaniel@gmail.com

My supervisors are:

Prof. Catherine Chong, **catherine.chong@humber.ca**

Prof. Sandro Zaccolo, **sandro.zaccolo@humber.ca**

HUMBER
Faculty of Applied Sciences & Technology
Bachelor of Industrial Design / FALL 2021 & WINTER 2022

IDSN 4002 / 4502
SENIOR LEVEL THESIS ONE & THESIS TWO

PARTICIPANT INFORMED CONSENT FORM

Research Study Topic: How may we improve the transportation of critical care patients to be more effective?
Investigator: Raymond Daniel / 250-217-6367 / raykdaniel@gmail.com
Courses: IDSN 4002 & IDSN 4502 Senior Level Thesis One & Two

I, Barrie Martin *(First Name/Last Name)*, have carefully read the Information Letter for the project How may we improve the transportation of critical care patients to be more effective, led by Raymond Daniel. A member of the research team has explained the project to me and has answered all of my questions about it. I understand that if I have additional questions about the project, I can contact Raymond Daniel at any time during the project.

I understand that my participation is voluntary and give my consent freely in voice recording, photography and/or videotaping; with the proviso that my identity will be blurred in reports and publications.

Consent for Publication: Add a (X) mark in one of the columns for each activity

ACTIVITY		YES	NO
Publication	I give consent for publication in the Humber Library Digital Repository which is an open access portal available to the public	☑	☐
Review	I give consent for review by the Professor	☑	☐

Privacy
All data gathered is stored anonymously and kept confidential. Only the principle investigator /researcher, Raymond Daniel and Prof. Catherine Chong or Prof. Sandro Zaccolo may access and analyze the data. All published data will be coded, so that visual data is not identifiable. Pseudonyms will be used to quote a participant (subject) and data would be aggregated.

I also understand that I may decline or withdraw from participation at any time, without negative consequences.

I understand that I can verify the ethical approval of this study, or raise any concerns I may have by contacting the Humber Research Ethics Board, Dr. Lydia Boyko, REB Chair, 416-675-6622 ext. 79322, **Lydia.Boyko@humber.ca** or Raymond Daniel, 250-217-6367, raykdaniel@gmail.com.

Verification of having read the Informed Consent Form:

☑ I have read the Informed Consent Form.

My signature below verifies that I have read this document and give consent to the use of the data from questionnaires and interviews in research report, publications (if any) and presentations with the proviso that my identity will not be disclosed. I have received a copy of the Information Letter, and that I agree to participate in the research project as it has been described in the Information Letter.

Barrie Martin	Barrie Martin	October 13 2021
Participant's Name	Participant's Signature	Date

3

Gmail Ray Daniel <raykdaniel@gmail.com>

Thesis Topic Chosen!

4 messages

Ray Daniel <raykdaniel@gmail.com> Wed, Sep 22, 2021 at 8:37 PM
To: MARTIN <bmartin99@rogers.com>

Hi Barrie,

I hope you are doing well.

Good news, my professors have selected a thesis problem statement that is in the general direction of what we had discussed over the summer. Currently the working title of the project is as follows:

Improving the Effectiveness of Transporting Critical Care Patients.

At this point, I need to perform high level research, followed by more indepth research.

I was wondering if you were free sometime **this week** to have a **10 to 20 minute interview** over the **phone or video chat**? With your consent, I would like to audio record the session for more accurate coding. The times that I am available are listed below:

- Thursday, September 23 (tomorrow) - after 8:30 pm
- Friday, September 24 - all day
- Saturday, September 25 - all day

The interview would allow me to gain a broader understanding of your position and get a general sense of potential pain points both you and your colleagues experience on the job. Additionally, there will be some focus on difficulties experienced immobilizing and transporting spinal injury patients. The information provided will be made anonymous. That being said, by no means are you obligated to do this interview.

Let me know if you are interested and I will send you a consent form.

Looking forward to hearing from you soon!

Regards,

Ray Daniel
250-217-6367

MARTIN <bmartin99@rogers.com> Thu, Sep 23, 2021 at 9:24 PM
To: Ray Daniel <raykdaniel@gmail.com>

Hi Ray great to hear you have a thesis direction. I'm available tomorrow (Friday) around 0930 hrs. Sorry for the late reply. Hope this works for you.
Barrie Martin

Sent from my iPhone

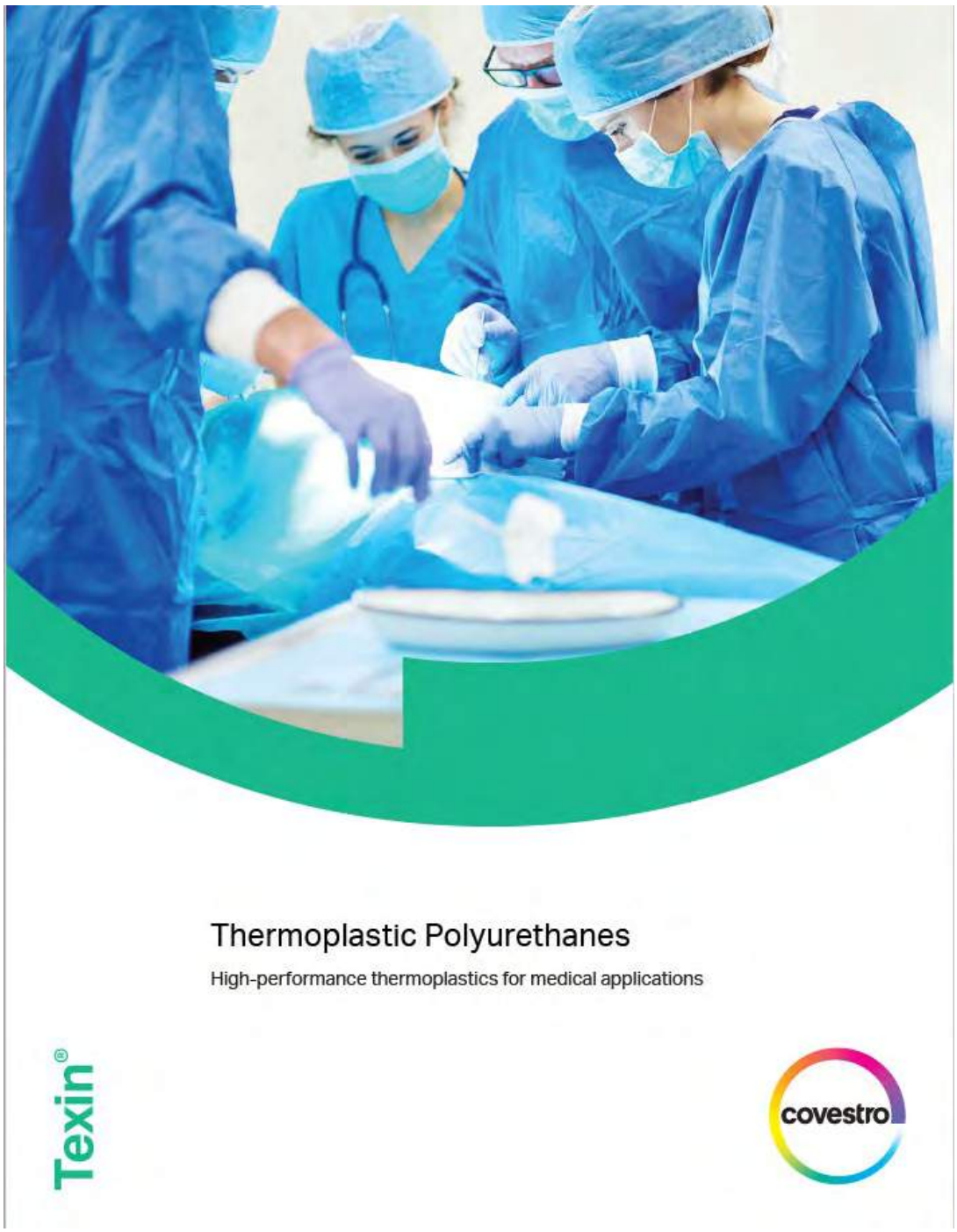
> On Sep 22, 2021, at 8:37 PM, Ray Daniel <raykdaniel@gmail.com> wrote:
>
> [Quoted text hidden]

Ray Daniel <raykdaniel@gmail.com> Thu, Sep 23, 2021 at 11:10 PM

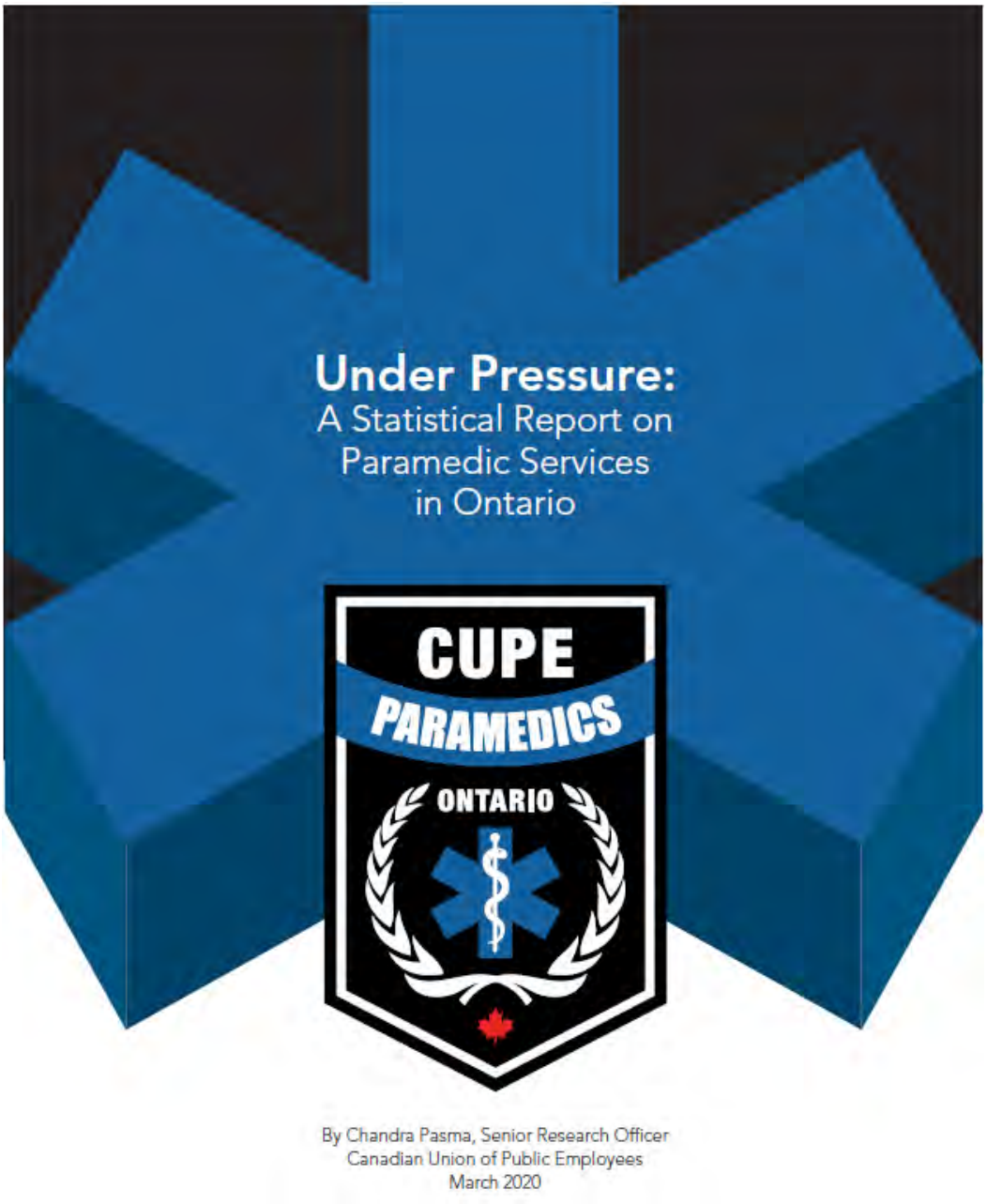
Appendix L – Other Supportive Raw Data

Appendix L – Topic Specific Data, Papers, Publications

Covestro has a great number of resources on their well laid out website https://www.covestro.com/en one of these references talks about their product Texin which is used in medical grade flexible products.



The CUPE annual report outlines most of the offload delay issues that Ontario paramedics and hospitals are experiencing. The report also outlines some of the issues with overworked paramedics, something that is a serious issue but is outside the scope of this project.



The following report describes a study completed in Ontario about issues of communication during patient hand over.

ORNGE SUPPLEMENT

Clinical handover from emergency medical services to the trauma team: A gap analysis

Arshia P. Javidan, BHSc*†‡; Avery B. Nathens, MD, MPH, PhD†‡§; Homer Tien, MD, MSc†§; Luis T. da Luz, MD, MSc†§

CLINICIAN'S CAPSULE

What is known about the topic?
Clinical handover between emergency medical services (EMS) and emergency departments (ED) and/or the trauma team is suboptimal and can compromise patient safety.

What did this study ask?
What are handover patterns and areas for improvement between EMS and the trauma team at Canada's largest trauma centre?

What did this study find?
Handover characteristics included a lack of active listening, discordant expectations between team members, and inconsistency in content and structure.

Why does this study matter to clinicians?
Handover quality improvement in the setting of trauma can reduce critical incidents, optimize team performance, and improve patient care.

ABSTRACT

Objectives: There has been limited evaluation of handover from emergency medical services (EMS) to the trauma team. We sought to characterize these handover practices to identify areas of improvement and determine if handover standardization might be beneficial for trauma team performance.

Methods: Data were prospectively collected over a nine-week period by a trained observer at a Canadian level one trauma centre. A randomized scheduled was used to capture a representative breadth of handovers. Data collected included outcome measures such as duration of handover, structure of the handover, and information shared, process measures such as questions and interruptions from the trauma team, and perceptions of the handover from nurses, trauma team leaders and EMS according to a bidirectional Likert scale.

Results: 79 formal verbal handovers were observed. Information was often missing regarding airway (present 22%), breathing (54%), medications (59%), and allergies (54%). Handover structure lacked consistency beyond the order of identification and mechanism of injury. Of all questions asked, 35% were questioning previously given information. The majority of handovers (61%) involved parallel conversations between team members while EMS was speaking. There was a statistically significant disparity between the self-evaluation of EMS handovers and the perceived quality determined by nurses and trauma team leaders.

Conclusions: We have identified the need to standardize handover due to poor information content, a lack of structure and active listening, information repetition, and discordant expectations between team members. These data will guide the development of a co-constructed framework integrating the perspectives of all team members.

RÉSUMÉ

Objectifs: Peu d'études ont porté sur l'évaluation du transfert de responsabilité clinique, ou de soins, des services médicaux d'urgence (SMU) à l'équipe de traumatologie. L'étude visait donc à caractériser les pratiques relatives au transfert de soins afin de cerner les points à améliorer et de déterminer si l'uniformisation du transfert de soins permettrait d'accroître la performance de l'équipe de traumatologie.

Méthode: Un observateur formé a procédé à la collecte prospective de données sur une période de 9 semaines, dans un centre de traumatologie de niveau 1, au Canada, selon une répartition aléatoire de l'horaire afin de constituer un échantillon représentatif des transferts de soins. Les données recueillies reposaient sur des critères d'évaluation tels que la durée du transfert de soins, la structure du transfert de soins et la communication de renseignements, ainsi que sur des mesures de processus comme des questions ou des interruptions par l'équipe de traumatologie, et les perceptions du personnel infirmier, des chefs d'équipe de traumatologie et des

*From Faculty of Medicine, University of Toronto, Toronto, ON; †Tory Regional Trauma Program and the Evaluative Clinical Sciences Program, Sunnybrook Research Institute, Toronto, ON; ‡Institute of Health Policy, Management, and Evaluation, University of Toronto, Toronto, ON; and §Department of Surgery, Sunnybrook Health Sciences Centre, Toronto, ON.

Correspondence to: Arshia Pedram Javidan, Faculty of Medicine, University of Toronto, 1 King's College Circle, Toronto, ON M5S 1A8; Email: Arshia.javidan@mail.utoronto.ca

 CJEM 2020;22(Suppl 2):S21–S29 DOI 10.1017/cem.2019.438

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