X-strap

Prepared for:
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Lurie Children’s Hospital
Transport Team

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Executive Summary

Our client, Ms. Laura Westley, is the senior director of interfacility transport at Ann & Robert H. Lurie Children's Hospital. Her team recently acquired a product called the Transportle*,* which houses preterm infants during interfacility transport. While there are many upsides to this device, Ms. Westley approached us with a concern about the velcro restraints that come with the Transportle; namely, that these restraints are inadequate to protect the neonate during a serious ambulance crash. In addition, these velcro straps require the medical staff to constantly reach over the infant, causing maneuvers that are uncomfortable for the staff and dangerous for the baby. After much research and testing, we determined three major needs that our solution must meet: safety (for the infant), ease-of-use (for the transport team), and durability (of the strap).

Our solution is the X-Strap. While the current design consists of four separate pieces that can become easily tangled with velcro, our solution consists of two straps joined together at an intersection with interlocking snap buttons, creating an 'X' shape. At the ends of the strap are more snap button studs, followed by pairs of sockets at discrete intervals away from one another, making it adjustable. As opposed to velcro, snap buttons can more easily be latched together without compromising on the strength of attachment, and are more long-lasting, making it an appealing choice. Next, the strap is composed of a rigid yet flexible padded aluminum sheet. This material allows for a safer, but also comfortable, experience for the infant. In addition, because of the rigidity of the aluminum sheet, the strap is able to remain freestanding in between transports. This is extremely advantageous to the transport team because it reduces the need to reach over the infant when strapping; instead, one can simply bring down the straps when needed and push up the straps when they are not. Ultimately, the strap is wrapped in a breathable, water-repellent cotton fabric in order to both prevent skin irritation for the infant and provide an easy cleaning experience for the transport team. In all, these components work together to meet the previously described user needs.

Introduction

Our project partner, Ms. Laura Westley, the Senior Director of Interfacility Transport **[1]**, tasked our design team with the challenge of developing an innovative solution to a safety problem posed by a device used to transport preterm infants (see *Appendix A: Background Research Summary*), called the *Transportle* ~ (Figure 1). The main two components of this product are the docking station ~ (Figure 2) ~ and the Womba Pod ~ (Figure 3). The Womba Pod houses the infant and comes with smaller straps of its own, while the docking station provides padding between the Womba Pod and the tray upon which the entire Transportle rests. According to the medical staff at Lurie Children's Hospital, the Transportle provides numerous benefits, as it: maintains warmth for the infant, comes with developmental accessories, like the Tortle (which aids in stabilizing the head), and also accommodates other necessary medical equipment like respiratory support and IV tubes. However, they hold a serious concern about the additional, outer velcro straps ~ (Figure 4) ~ used to secure the Transportle to the isolette. In the current design, the provided additional velcro restraints inadequately secure the infant to the Transportle, increase safety risks by necessitating medical staff to reach over the neonate, and complicate an otherwise user-friendly device (see *Appendix B: First Project Partner Interview Summary*).

Figure 1: Transportle in Mock Isolette

Figure 2: Docking Station

Figure 3: Womba Pod

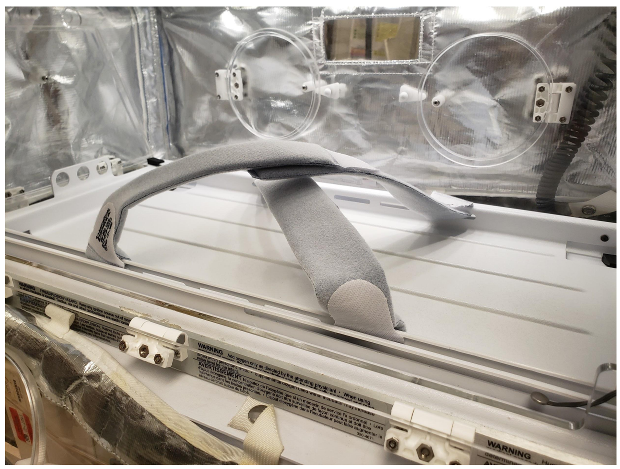


Figure 4: Additional Velcro Straps [2]

Many members of the transport team at Lurie Children's Hospital, including Ms. Westley, Ms. Tracy Rojas[1], and Ms. Sheila Nally[2], expressed their concern with the usage of velcro in the straps, noting they had abandoned velcro nearly eight years ago in favor of buckle straps (see *Appendix C: Second Project Partner Interview Summary)*. Their main fear was that velcro would inadequately secure the infant in the event of a major ambulance crash. In addition, they echoed the unease of reaching over to restrain the baby ~ (Figure 5).

[1] The Lurie Children's Hospital transport team education coordinator
[2] The transport team's safety coordinator and equipment liaison

Figure 5: Demonstration of Velcro Straps Application

Instead, our proposed design ~ (Figure 6/7) ~ meets three important needs that the current design lacks: **Safety**, **Ease-of-Use**, and **Durability** (These will be further detailed later on). The modified design utilizes two continuous straps, conjoined at an intersection to form an 'X,' lined internally with a padded aluminum sheet, and latched together with snap buttons. This allows for a more intuitive and efficient experience for the transport team, as well as a safer experience for the neonate.

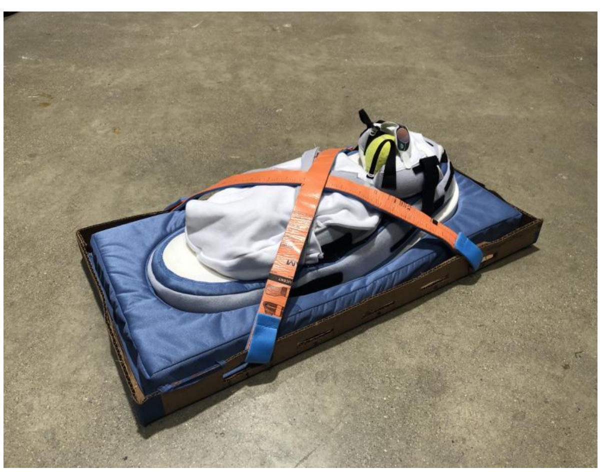


Figure 6: X-Strap without Cloth Covering

Figure 7: X-Strap with Cloth Covering

Users

Primary

The primary users of this design are the transport team and medical staff at Ann & Robert H. Lurie Children's Hospital. This team encompasees first responders, EMTs, ambulance workers, and receiving hospital staff, as defined on Lurie's website **[3]**. They engage in time-sensitive interfacility transport of critically ill neonates, as the health of the baby is largely determined by the successful delivery of the infants from the ambulance to the hospital's Neonatal Intensive Care Unit (NICU). These individuals are the immediate operators of the Transportle and its supplementary straps and directly affect its usage.

The transport team primarily cares for preterm infants, the other primary user group and for whom our product is designed to protect. These neonates are typically born after just 32 weeks of gestation and weigh at or below 1500 grams. As a result, they are especially vulnerable to sudden movements or external vibrations caused by stop-and-go traffic and general turbulence of ambulance rides. This group is the immediate users of the Transportle and straps, and so it is extremely crucial to frame the design around the safety of these premature infants.

Secondary

Secondary users include the parents of infants being transported. They are the legal guardians of these individuals and thus are responsible for them. Parents also make the request for an ambulance to transport their children, thus acting as an intermediary between the transport team and their baby.

Requirements

The following requirements were primarily determined from initial interviews with the clients and Performance Testing of the existing system (see *Appendix D: Project Definition* for greater elaboration on Users & Requirements).

The solution must:

1) Ensure the safety of the infant, especially in the event of a major ambulance crash

The modified design must ensure that the restrained infant is firmly secure in the Transportle. This entails limiting the internal movements the baby experiences, such as sudden motions caused by bumps on the road, as well as providing securements that can withstand large normal and shear forces exerted onto the X-Strap.

2) Be easy to use by the transport team and medical staff

The new solution must allow for a smooth, intuitive experience for the transport team to strap the neonate. The parts of the design must ensure the transport process is completed in a timely manner, that the baby can be strapped with minimal assistance, and that the design does not obstruct any necessary medical equipment. Efficiency of the process must be maximized because the hospital deals with extremely time-sensitive tasks, and saving time with menial tasks allows greater allocation of focus toward the safety of the infants.

3) Curb the need to reach over the Transportle when securing the infant

This concern brought up a multitude of times by the clients must be accounted for in the X-Strap. It is imperative that the design provides a means to reduce the need to excessively reach over the infant during the strapping process such that unintentional injuries to the infant are avoided, thereby reducing safety concerns (see *Appendix E: User Feedback Summary*).

4) Be durable, long-lasting, and cleanable

Creating straps that can withstand multiple cycles of use is indicative of a robust and long-lasting device. Having this longevity and reliability is important because it allows the transport team to focus on the safety of the infant instead of worrying about turnover (thus increasing the efficiency of the transport process). To fully consider reusability, our design should be easily cleaned as well.

Design Concept & Rationale

Overview

Our design ~ (Figure 8) ~ is an 'X-shaped' strap, conjoined at its intersection with snap buttons. These interlocking snap buttons are also used to tighten and adjust the strap. The strap is composed of a padded, rigid material called Sam Splint, and is ultimately covered in soft, water-repellent cotton fabric (see *Appendix F: Bill of Materials*, *Appendix G: Instructions for Construction*, and *Appendix H: Instructions for Using Prototype*). The following sections describe individual features of the overall design, as well as the rationale behind implementing each portion.

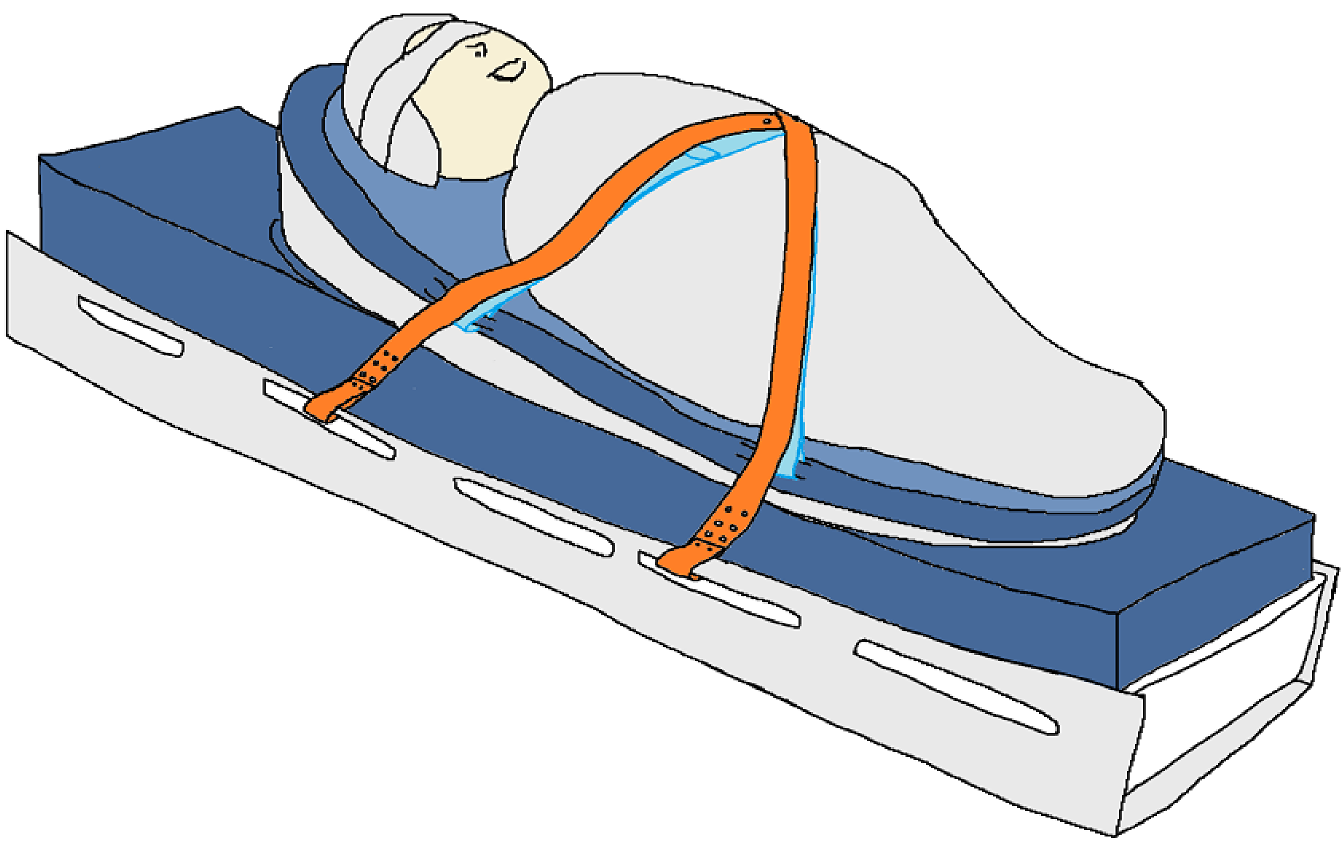


Figure 8: The X-Strap in Action

X-strap

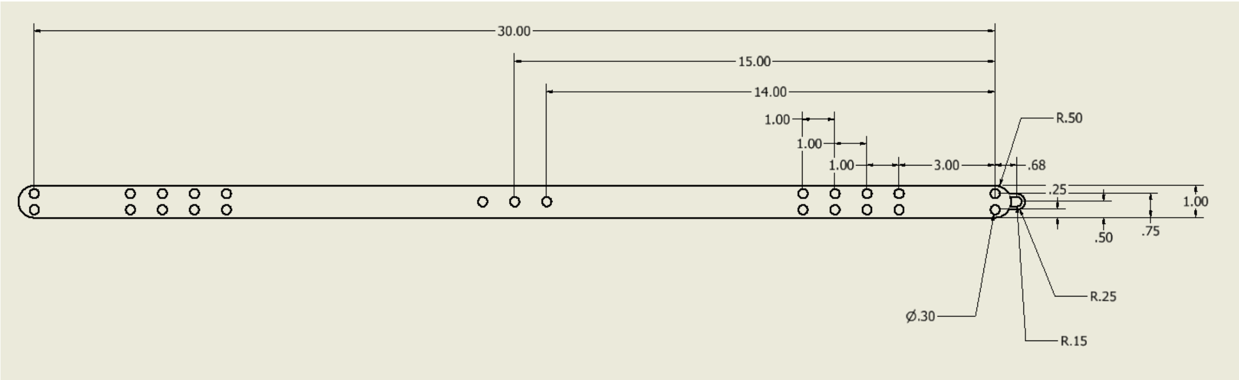


Figure 9: Dimensioned, Orthographic Drawing of a Single Strap in the X-Strap (In Inches)

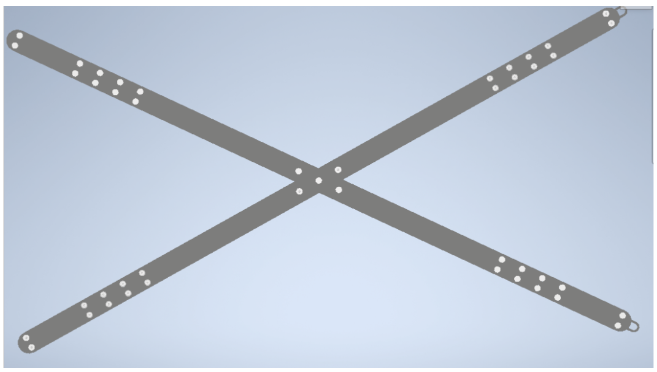


Figure 10: Top-Down View of the X-Strap

Concept

The X-strap is composed of a padded aluminum sheet (explained later), taped on the edges with duct tape, and wrapped in a cotton fabric sheet. Rather than four individual straps that the Transportle is currently using, the new design implements two straps, each 30" long, 1" wide, and 0.25" thick ~ (Figure 9). The straps are conjoined to form the shape of an 'X' ~ (Figure 10) The center of this X is adjustable with five upward facing 0.3" aluminum sockets on the bottom strap (0.5" gap from one another), and one downward-facing 0.3" aluminum stud on the top strap. At each tail of the strap are the same 0.3" studs and corresponding pairs of sockets at discrete lengths of 1" away. There are also cotton pull tabs of radius 0.15" through holes at the ends of these tails.

Rationale

Utilizing these two continuous straps that easily link with a snap button limits the need for the medical staff to reach over the infant when securing the restraints. The multiple attachment points near the intersection allows the transport team to shift the center of the 'X' if it deviates away from the infants midline. In addition, the complexity of the securement process is significantly reduced with one strap, as opposed to four separate pieces like in the original (see *Appendix I: Shop Consultations*). The pull tabs at the ends of the strap aids in unlatching the snap buttons (see *Appendix J: Design Review Summary*); the loop nature of these pull tabs are ideal because they can more easily be grasped by a finger. Finally, the padded aluminum sheet adds rigidity and flexibility to the strap, and the layer of water-repellent cotton fabric sheet is easily cleanable and helps avoid skin irritation to the neonate. Therefore, these modifications meet two significant user needs: safety and ease-of-use.

Padded Aluminum Sheet

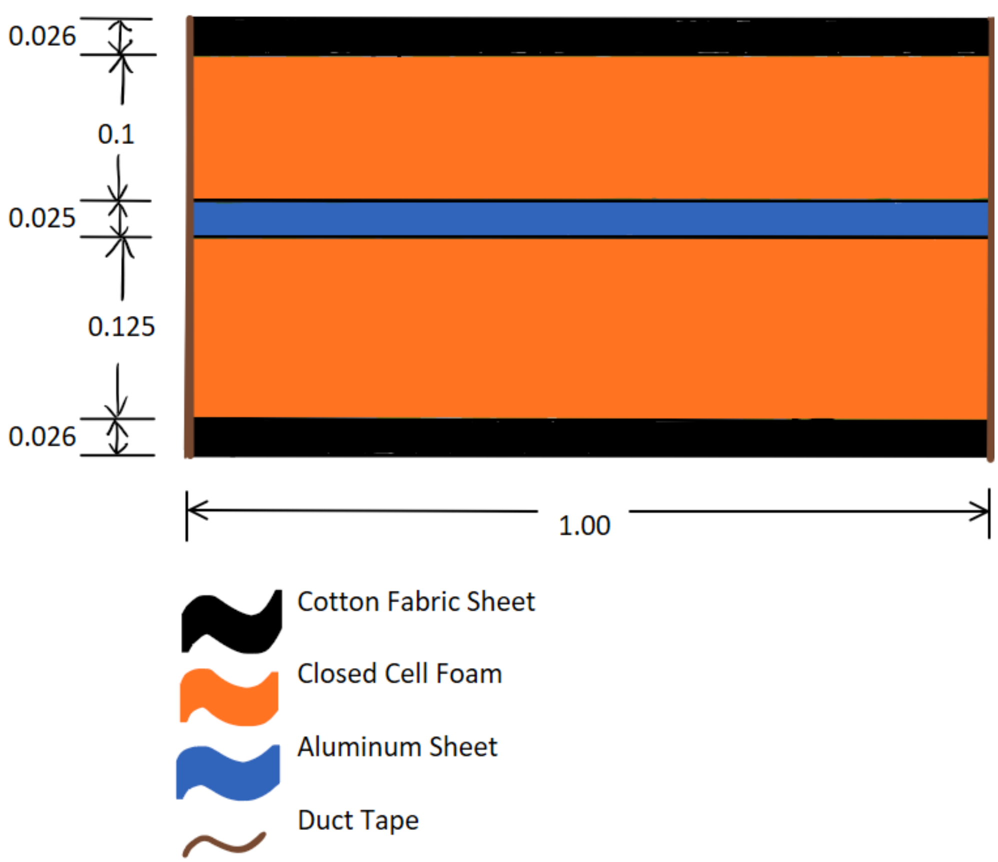


Figure 11: Cross Section of the X-Strap (in Inches)

Figure 12: Freestanding X-Strap (Side) *Figure 13: Freestanding X-Strap (Front)*

Figure 14: Demonstration of X-Strap Application

Concept

The padded aluminum sheet is a rigid and flexible material composed of an aluminum sheet (0.025”), cushioned with (0.1”) closed cell foam on the top and (0.125”) in foam on the bottom. The entire material is enveloped in a cotton fabric sheet (0.026”. thick), and taped on the edges with Duct tape ~ (Figure 11).

Rationale

Incorporating a padded aluminum sheet into the design of the splint introduces rigidity, and thus increased safety for the straps but also flexibility in molding the restraints to conform to the baby's body. Then, the closed cell foam surrounding the aluminum sheet proves a soft barrier to the hard metal as well as a cushion to the baby. The added duct tape is another safety measure to ensure that there is proper padding between the infant and rigidity of the aluminum sheet in the strap. This material limits internal movement of the infant caused by light road turbulence due to its rigidity, but also can reconfigure shape if greater force is applied (see *Appendix K: Performance Testing*). Therefore, in the event of a serious crash, the flexible nature of the strap, as well as the foam cushion, will more gracefully hold the baby while still providing proper securement. Another advantage of this padded aluminum is its ability to remain freestanding ~ (Figure 12/13). Thus, when the straps are not in use in between transits, they can remain propped up until the next infant needs to be moved and pulled downwards to readjust for the next transport ~ (Figure 14). Not only is this extremely efficient and intuitive to use, it drastically reduces the need to reach over the infant, checking a safety concern with the current velcro restraints.

Snap Buttons

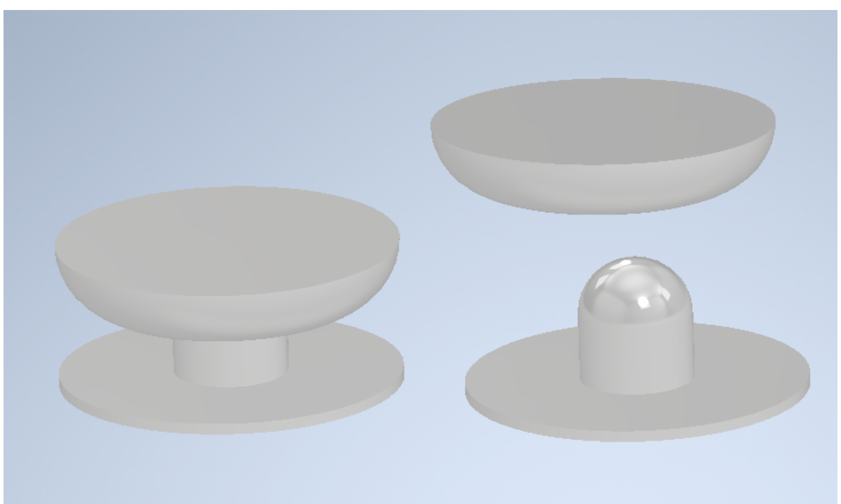
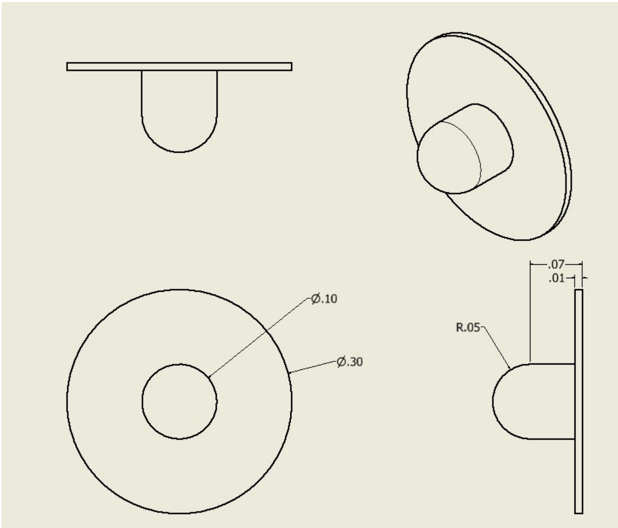


Figure 15: Visualization of Snap Buttons



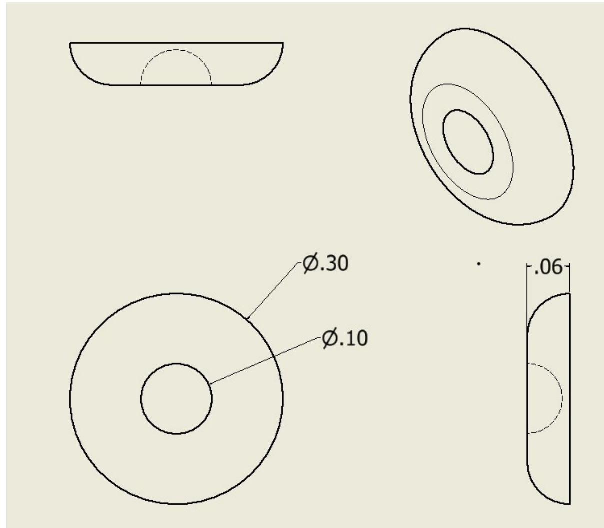


Figure 16: Dimensions of Stud (Inches) ***Figure 17: Dimensions of Socket (Inches)***

Concept

The Snap Buttons ~ (Figure 15) ~ consist of two parts: the inserting stud ~ (Figure 16) ~ and the holding socket ~ (Figure 17), each with 0.3" diameter. The type of stud used is a closed stud while the socket used is a parallel spring socket **[4]**, which together provide noiseless and effortless snaps. The placements of these Snap Buttons are detailed previously.

Rationale

Not only do Snap Buttons demonstrate sufficient strength and resistance to shear forces (see *Appendix K: Performance Testing*), better than that of velcro straps, but they are far less complicated to use. Because there are discrete but easy-to-reach attachment points, it is far easier to latch and readjust the straps. While handling velcro is rather complicated and leads to many unintended connections, due to its nature of quickly latching onto other velcro surfaces, the motions with snap buttons have to be intentional - that is, one cannot latch and unlatch snap buttons accidently. Snap buttons have proven to be superior to velcro in both safety and ease-of-use, and would thus enhance the experience of the transport team and safety for the neonate. Further hands-on testing, as well as approval from the client has led us to believe that snap buttons in tandem with the padded aluminum sheet are an effective restraint system that is both more secure and straightforward to use compared to the previous method

Limitations & Future Development

Due to the ongoing pandemic and COVID-19 restrictions, our ability to work on physicalizing our designs have been strained, and visiting the transport team at Lurie's Children's Hospital is also prevented. In addition, there has been no previous neonatal mannequin crash testing in America. Thus, it was difficult to attain quantitative data.

One limitation of the design is that our primary material, the padded aluminum sheet, was bought as a consumer product (SAM Splint) with only one width choice available in the market (4.25") - approximately four times the desired width of our design. Because this forces the manufacturer to make three cuts in order to adapt to our size requirement and since SAM Splint contains an aluminum sheet in its interior, cutting through the material would result in sharp edges on the sides of the X-strap. Our team wrapped around the sides using duct tape to smoothen out the edges before covering everything in cotton fabric, but others may pad these edges with foam moving forward.

In addition, the ratio of aluminum sheet to foam padding is constant in the SAM Splint. This restricted our team's ability to determine the proper balance of aluminum and foam such that the SAM Splint could best support its weight. As of now, the manufacturer must implement the SAM Splint as delivered, even if the current composition of the material makes it more difficult for an unused SAM Splint to remain propped up. In the future, it may be beneficial for the manufacturer to build and test their own SAM Splint-like material, to optimize the product for neonate restraints.

One last consideration for the manufacturer is to have a better sewing method utilizing specific push button pliers that were not available to us. A set of push buttons consists of a post that goes with a stud and a cap that goes with a socket. Instead of punch riveting and hand sewing, each pair (post and stud, cap and socket) could be attached on the nylon cloth by pushing together through the pliers. This way is both time-saving and more efficient.

Conclusion

After careful and thoughtful secondary research, primary research, and performance testing, our team was able to understand and internalize the challenge at hand, compile numerous amounts of solutions, rigorously filter through the various ideas, and arrive at a design which meets the important needs. The efficacy of our design arises from the contributions of several modifications, the main ones being: two easily attachable restraints (to form the X-strap), a padded aluminum sheet with a Water-Repellent Cotton Fabric covering, and Snap buttons. The X-Strap is more concise, the Snap Buttons are more intuitive, and the padded aluminum is safer than the current solution. In total, each implemented idea fulfills all of the previously stated user needs, broadly: Safety, Ease-of-use, and Durability. While there are more directions that this design can take, the foundations for this concept is set and the implementation was successful.

References

[1] "Nursing Leadership Team," *Lurie Children's*. [Online]. Available: https://www.luriechildrens.org/en/for-healthcare-professionals/nursing/leadership-team/. [Accessed: 16-Jan-2021].

[2] Photo Credit: Grant Galatas & Erin Park, Lurie Children's Hospital

[3] "Transport Team," Lurie Children's. [Online]. Available: https://www.luriechildrens.org/en/specialties-conditions/pediatric-emergency-room/transport-team/. [Accessed: 16-Jan-2021].

[4] "Snap Fasteners," *Snap Fasteners from Rome Fastener*. [Online]. Available: https://www.romefast.com/Snap-Fasteners.asp. [Accessed: 26-Feb-2021].

Appendix A: Background Research Summary

I. Introduction

In preparation for this project, as well as upcoming primary research and design prototyping, a selection of secondary research was conducted across various teams. One group prepared research concerning the formal definitions of preterm infants and how medical care is provided to these babies. A second group researched the Transportle itself, including its mechanics, design, usage, advantages, and limitations. A third group researched alternative devices to the Transportle, coming across several designs and patents, both in use and prototypes. They also analyzed the pros and cons of each respective design. Our end of the secondary research process involved understanding the background of the hospital itself. <u>What are they, what do they do, and who do they serve?</u>

II. General Background

Figure A1: Main Facility

Figure A2: NICU Center

Founded in 1882 by Julia Foster Porter as a simple eight-bed cottage **[5]**, Ann & Robert H. Lurie Children's Hospital of Chicago ~ (Figure A1) ~ has now become a renowned non-profit, pediatric acute care and teaching hospital. As a teaching hospital, Lurie's Children Hospital is partnered with Northwestern's Feinberg School of Medicine, allowing graduate students to partake in ongoing research, as well as Northwestern Memorial Hospital. Lurie Children's Hospital also has affiliations with Prentice Women's Hospital and Shirley Ryan Ability Lab **[6]**. Lurie Children's Hospital is a reputable hospital, as it is nationally recognized **[7][8]** in several separate specialties, including but not limited to its Neonatal Intensive Care Unit ~ (NICU, Figure A2) ~ (A full list of the specialties can be found on their website.) Their NICU is designated a Level IV facility, the highest such designation specified by the American Academy of Pediatrics (AAP), as well as one of seven such NICU's in the state of Illinois **[9]**. As a Level IV NICU, they provide care to the most critically ill infants, especially children born after just 32 weeks of gestation. Below is a table provided by the state of Illinois that explains in more detail the distinctions between the various level facilities ~ (Figure A3).

Level of Care	Definition	Examples of Capabilities	Examples of Providers	Key Differences from IDPH System
I	Well newborn nursery	• Provide neonatal resuscitation at every delivery • Evaluate and provide postnatal care to stable term newborn infants • Stabilize and provide care for infants for 35-37 wk gestation who remain physiologically stable • Stabilize newborn infants who are ill and those born at <35 wk gestation until transfer to higher level of care	Pediatricians, family physicians, nurse practitioners, and other advanced practice registered nurses	• IDPH Level I only allows for care ≥37 weeks; AAP would also allow stable 35-36 week infants to stay in Level I
II	Special care nursery	Level I capabilities, plus: • Provide care for infants born ≥32 wk gestation and weighing ≥1500 g who have physiologic immaturity or who are moderately ill with problems that are expected to resolve rapidly and are not anticipated to need subspecialty services on an urgent basis • Provide care for infants convalescing after intensive care • Provide mechanical ventilation for brief duration (<24 h) or continuous positive airway pressure or both • Stabilize infants born before 32 wk gestation and weighing less than 1500 g until transfer to a neonatal intensive care facility	Level providers, plus: Pediatric hospitalists, neonatologist, and neonatal nurse practitioners	• IDPH Level IIs can ventilate only up to 6 hours; AAP allows up to 24 hours • IDPH has Level II-E, which is not included in AAP
III	Neonatal Intensive Care Unit (NICU)	Level II capabilities, plus: • Provide sustained life support • Provide comprehensive care for infants born <32 wks gestation and weighing <1500 g and infants born at all gestational ages and birth weights with critical illness • Provide prompt and readily available access to a full range of pediatric medical and surgical subspecialists • Provide a full range of respiratory support • Perform advanced imaging, with interpretation on an urgent basis, including computed tomography, MRI, and echocardiography	Level II providers, plus: Pediatric medical sub-specialists*, pediatric anesthesiologists*, pediatric surgeons, pediatric ophthalmologists* *(*may be at the site or at a closely related institution by prearranged consultative agreement)*	• AAP allows telemedicine for provision of some services • AAP gives flexibility in types of surgical coverage
IV	Regional NICU	Level III capabilities, plus: • Located within an institution with the capability to provide surgical repair of complex congenital or acquired conditions • Maintain a full range of pediatric medical subspecialists, pediatric surgical subspecialists, and pediatric anesthesiologists at the site • Facilitate transport and provide outreach education	Level III providers, plus: Pediatric surgical sub-specialists	• No IDPH Level IV: The AAP Level IV distinguishes facilities with extensive surgical capacity and subspecialist availability

Figure A3: Neonatal Levels of Care: AAP Policy Compared to IDPH Perinatal System

The NICU at Lurie Children's Hospital cares for more than 2,000 infants each year, but they also have direct access to the aforementioned Prentice Women's Hospital, which manages more than 30,000 births per year **[10]**. The descriptions of the NICU at Lurie Children's Hospital stresses the importance of punctual and all-encompassing medical attention and pronounces the need for safe and effective transport of preterm infants. Therefore, our team clearly understands the significance of addressing any safety concerns that may arise regarding the *Transportle*.

Finally, Lurie Children's Hospital also invests enormous resources toward its research as well as community-focused initiatives outside the hospital. Through partnership with Stanley Manne Children's Research Institute (designated a Northwestern University Feinberg School of Medicine research center), Lurie Children's Hospital is heavily involved in research innovations in several fields relating to pediatric diseases **[11]**. Staffed with more than 200 investigators, 500 staff members and 100 trainees **[12]**, the research team is constantly attempting to understand the root causes of adolescent diseases, including in the field of neonatology, and ways to prevent and cure them. (Read about their ongoing Neonatology Research here.) In addition, Lurie Children's Hospital has partnered with Patrick M. Magoon Institute for Healthy Communities to promote general health of children in the surrounding community. They are especially focused on promoting the well being of children dealing with issues of "racism, poverty, poor access to healthcare, housing insecurity, food insecurity, unemployment, violence, and an unsafe physical environment" **[13]**. These initiatives undertaken by the hospital further underscore their commitment to quality care and bettering the health of the immediate community.

III. Locations

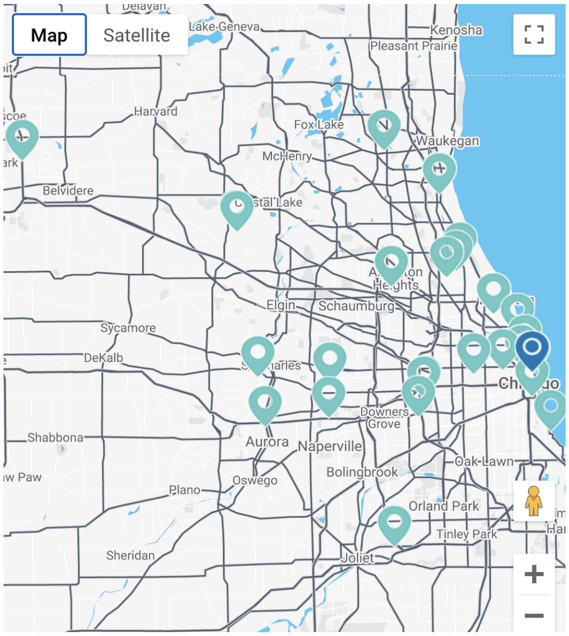


Figure A4: Lurie Facility Locations *Figure A5: 225 E. Chicago Ave. Locations*

Lurie Children's Hospital has 35 total locations ~ (Figure A4): four of their locations are in partnerships with Northwestern, while the rest are mainly outpatient care centers **[14]**. The main hospital is located on 225 E. Chicago Ave. ~ (Figure A5); it houses the most patients, staffs the most beds **[15]**, and gains the most patient referrals. Given the urban and central location of this main hospital, and since the hospital acts as a hub where ambulances constantly transport patients to and from the main facilities, the roads near the main hospital experience a sizable amount of traffic ~ (Figure A6).

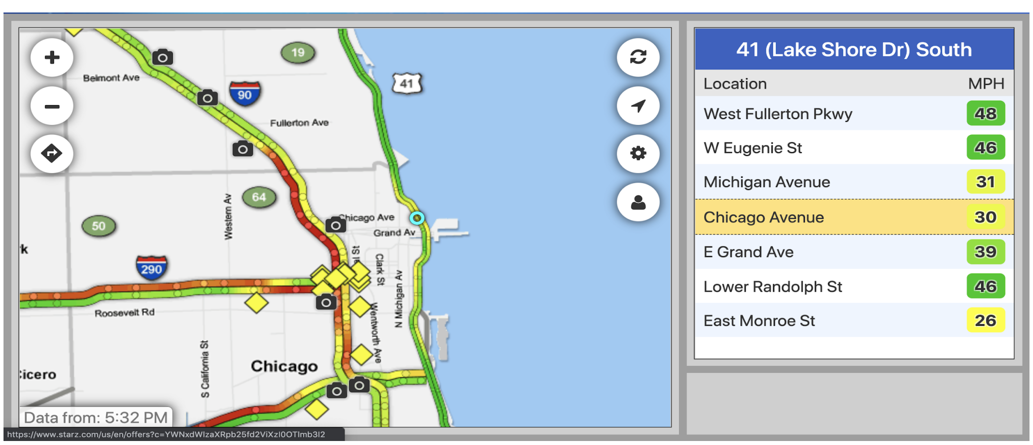


Figure A6: Chicago Traffic Map near Chicago Ave. at 5 PM CST

As a result, it is not only pertinent to design a modification to the Transportle to ensure safety in the event of an ambulance crash, but it is also important to remain mindful of stabilizing en-route infants during stop-and-go traffic.

IV. Transport Team

Figure A7: Lurie Children's Hospital's Transport Team's Logo

Since the transport team ~ (Figure A7) ~ is a main user of the Transportle, our team found it necessary to learn how this specific team operates. The transport team at Lurie Children's Hospital provides high-class, 24/7 assistance to even the most critically ill patients, including neonatal infants. Once again, as a Level IV NICU, the transport team is not only trained in essential medical practices, such as neonatal resuscitation, advanced cardiac life support, acure stabilization of the critically ill child, and more, but they also provide air and ground travel to ensure prompt medical attention at the hospital is received. As a result of these capabilities, the transport team at Lurie Children's Hospital has received numerous prestigious awards, including the CAMTS Accreditation (one of 13 in the country), the 2015 Association of Air Medical Services (AAMS) Neonatal and Pediatric Transport Award of Excellence, and the 2017 Critical Care Ground Award of Excellence **[16]**. It is therefore crucial that we heavily listen to the considerations of the transport team when prototyping designs for an improved restraint system for the Transportle.

V. Contacts

Our team compiled an initial list of contacts from whom necessary primary information may be gathered, as well as general contact information of the hospital.

- *Ann & Robert H. Lurie Children's Hospital of Chicago (Main Hospital):* **312-227-4000**
- *Transport Team:* **1-855-587-4363**
- *Worldwide International Biomedical*:
  - **8206 Cross Park Drive; Austin, TX 78754**
  - **Toll Free: +1-800-433-5615**
  - **Phone: +1-512-873-0033**
  - **Fax: +1-512-873-9090**
  - **E-Mail: sales@bio-int.com**

VI. Conclusion

As a result of our team's initial secondary research, we learned to tailor our design toward the needs of the transportation team on account of many reasons: the transport team is evidently the backbone of the operations of the NICU, they face significant ground traffic and at times air traffic, and they play major roles in maintaining the health of the infant during transportation.

VII. Citations

[5] C. Tribune, "Children's Memorial Hospital history," *chicagotribune.com*, 05-Sep-2018. [Online]. Available: https://www.chicagotribune.com/news/ct-xpm-2012-04-29-ct-met-hospital-history-box-20120429-story.html. [Accessed: 16-Jan-2021].

[6] "Our Partnerships," *Lurie Children's*. [Online]. Available: https://www.luriechildrens.org/en/who-we-are/our-partnerships/. [Accessed: 16-Jan-2021].

[7] *U.S. News & World Report*. [Online]. Available: https://health.usnews.com/best-hospitals/pediatric-rankings/neonatal-care. [Accessed: 16-Jan-2021].

[8] "Specialties & Conditions," *Lurie Children's*. [Online]. Available: https://www.luriechildrens.org/en/specialties-conditions/. [Accessed: 16-Jan-2021].

[9] Bennett, A., 2016. *Maternal And Neonatal Levels Of Care In Illinois: Report For The Illinois Perinatal Advisory Committee, October 20, 2016*. [pdf]. Available: https://www.google.com/url?q=https://www.dph.illinois.gov/sites/default/files/publications/d ata-report-illinois-levels-care.pdf&sa=D&ust=1610819610852000&usg=AOvVaw3vG9Zc0gAXpwy6ns9Hy5MB [Accessed: 16-January-2021].

[10] "Neonatal Intensive Care Unit (NICU)," *Lurie Children's*. [Online]. Available: https://www.luriechildrens.org/en/specialties-conditions/neonatology/. [Accessed: 16-Jan-2021].

[11] "About Stanley Manne Children's Research Institute," *Lurie Children's*. [Online]. Available: https://www.luriechildrens.org/en/research/about/. [Accessed: 16-Jan-2021].

[12] "Who We Are," *Lurie Children's*. [Online]. Available: https://www.luriechildrens.org/en/who-we-are/. [Accessed: 16-Jan-2021].

[13] "Patrick M. Magoon Institute for Healthy Communities," *Lurie Children's*. [Online]. Available: https://www.luriechildrens.org/en/serving-the-community/magoon-institute-for-healthy-communities/. [Accessed: 16-Jan-2021].

[14] "Locations," *Lurie Children's*. [Online]. Available: https://www.luriechildrens.org/en/locations/. [Accessed: 16-Jan-2021].

[15] "Hospital Profile," *Ann & Robert H. Lurie Children's Hospital of Chicago*. [Online]. Available: https://www.childrenshospitals.org/Directories/Hospital-Directory/A-E/Ann--Robert-H-Lurie-Childrens-Hospital-of-Chicago. [Accessed: 16-Jan-2021].

[16] "Transport Team," *Lurie Children's*. [Online]. Available: https://www.luriechildrens.org/en/specialties-conditions/pediatric-emergency-room/transport-team/. [Accessed: 16-Jan-2021].

Figure A1: Derived from Northwestern Medicine, "Ann & Robert H. Lurie Children's Hospital of Chicago: Chicago, IL," *Northwestern Medicine*. [Online]. Available: https://www.nm.org/locations/ann-robert-h-lurie-childrens-hospital. [Accessed: 16-Jan-2021].

Figure A2: Derived from "Fetal Health Facilities," *Lurie Children's*. [Online]. Available: https://www.luriechildrens.org/en/specialties-conditions/fetal-health/our-facilities/. [Accessed: 16-Jan-2021].

Figure A3: See **[9]**

Figure A4: Derived from *Lurie Children's*. [Online]. Available: https://www.luriechildrens.org/. [Accessed: 16-Jan-2021].

Figure A5: Derived from **[14]**

Figure A6: "Downtown (Loop) Traffic Report," Sigalert. [Online]. Available: https://www.sigalert.com/Map.asp?lat=41.89361&lon=-87.64397&z=0. [Accessed: 13-Jan-2021].

Figure A7: See **[16]**

Appendix B: First Project Partner Interview Summary

I. Introduction

During our secondary research, we learned much about the hospital's background, the Transportle, alternative restraint patents, and general infant care. However, we still required a precisely defined problem as well as understanding the scope of our solution. We conducted primary research to further clarify the needs of the transport team and the problem at hand. Our goal was to determine what is expected of our solution and to attain additional information pertinent to the design process, answering questions such as: *how can we improve the* Transportle*? What is the scope of our solution? Which factors should we consider or prioritize in our brainstorming? What does the transport process involve?*

II. Methodology

Laura Westley, BSN, MSM, RN

Senior Director, Interfacility Transport, Emergency Services, Patient Access Center and Almost Home Kids

Length of time as a leader: Since 2011 at Lurie Children's, since 2006 in healthcare

Education: BSN, UW-Eau Claire; MSM, Cardinal Stritch University

Leadership motto: Great leaders don't set out to be a leader…they set out to make a difference. It's never about the role, always about the goal.

Figure B1: Ms. Laura Westley's Description

We conducted our primary research through an interview with our project partner Ms. Laura Westley, a Senior Director and overseer of the Transport Team at Lurie Children's Hospital ~ (Figure B1). The interview was scheduled for January 20 from 5:00 PM CST to 6:00 PM CST; if needed, Ms. Westley allotted time after 6:00 PM for additional questions. Due to COVID-19 restrictions, the interview took place remotely via Zoom. Three members of our team, Karthik

Subramanian, Winston Zhao, and Jake Gallardo, were available for the interview, actively taking notes and asking questions alongside the other teams of Section 10.

Figure B2: Zoom Interview with Ms. Westley

As preparation for the interview ~ (Figure B2), our team designated a scribe and prepared questions before the event. We started by asking for Ms. Westley's permission to record the interview so that those who cannot attend will still have access to the interview. We then made sure to establish rapport and develop an understanding of Ms. Westley's professional background before moving on to the primary concern of the interview: the Transportle. Our team is especially interested in further defining the problem with the Transportle and has prepared many questions to address this specifically.

III. Results

The results of our research are largely qualitative, due to the nature of an interview. We learned of several key takeaways, including:

1. Lurie Children's Hospital's number one concern is safety and thus ease of mind. The hospital is currently hesitant to use the Transportle due to it being a relatively new product. The hospital, and healthcare in general, subscribe to the practice of

evidence-based medicine. Implementing the Transportle before significant testing and experience is an unlikely option since Ms. Westley explained their current lack of complete confidence in the product. We are tasked with making the restraint system of this device safer.

2. Though it hasn't been used in practice much yet, Ms. Westley recognized the Transportle as a top-tier product. Few alternatives to it offer as much restraint capability, comfort, and temperature management for the infantile patient. She clarified that because of this, the scope of our design solution is essentially focusing on modifications to the restraint system as opposed to a complete overhaul.
3. The Transportle's design permits the use of additional medical equipment, such as IV tubing or oxygen masks, but it lacks the means to organize the equipment.
4. Budget is a secondary issue and doesn't need to be prioritized during the design process.

IV. Discussion

Analysis

1. Our role is to grant the transport team ease of mind and confidence in the safety of the *Transportle.* There isn't anything necessarily wrong with the device, only the uncertainty of a fledgling product. Therefore, we aren't expected to develop an entirely new transportation device, but rather modify and improve the Transportle as it is.
2. Ms. Westley clarified that our modifications to the Transportle will be focused on the restraint system specifically. Thus, we have the scope of our solution and understand that to improve the safety of the Transportle, we'll have to focus specifically on restraints.
3. A lack of organizational tools is another potential shortcoming of the Transportle. We can potentially implement this facet of design into our own modification, but we'd also require clarification as to whether this addition would be beneficial or not. If so, what would be ideal?
4. While extra factors still may play a role in the design process, Ms. Westley has assured us that the cost is essentially negligible. The Children's Hospital is granting us creative freedom, as long as we achieve our goal of improved safety.

V. Conclusion

Despite few limitations, such as the inability to meet in person and the lack of crash testing data, the interview with Ms. Laura Westley was a success and pivotal to defining the problem and identifying what is expected of our solution. Moving forward in our research, our focus must be determining the restrictive capabilities and restraint design of the Transportle, given that we are still unsure of this even though it's the scope of our solution. Our future research opportunities include an interview with Ms. Rojas, the Transport Team Education Coordinator, scheduled for January 28 at 11:00 AM CST. Two of our team members, Jake Gallardo and Karthik Subramanian, will attend this interview. We were also extended the opportunity to send two students from our section to visit the Children's Hospital and observe the transport process, guided by Sheila Nally, the Transport Team Safety Coordinator. We expect that they will be able to provide a detailed look at the Transportle's design, as well as what factors must be considered throughout the transport process. Lastly, to achieve a more holistic view of the Transportle, we will survey the entire transport team, asking them to list any complaints or praise they have for the *Transportle*. Once we've continued our research, we'll move forth into ideation and brainstorming our design solution.

VI. Citations

Figure B1**:** "Nursing Leadership Team," *Lurie Children's*. [Online]. Available: https://www.luriechildrens.org/en/for-healthcare-professionals/nursing/leadership-team/. [Accessed: 26-Jan-2021].

Appendix C: Second Project Partner Interview Summary

I. Introduction

During our secondary research and the first primary research with Ms. Laura Westley, we learned much about the background of our project and understood the scope of our solution. We understood our project to be about adjusting and improving on the secureness of the restraint system of the Transportle, a device to transport neonatal infants in isolette. However, the exact failures of the Transportle had still been ambiguous to us as we have not seen a physical product. We conducted another primary research to further clarify what is expected of our solution. Our goal was to determine the restrictive capabilities and restraint design of the Transportle, as well as understanding the functions of the Transportle and its correlation with the isolette system.

II. Methodology

We conducted our second primary research through an interview with our project partner Ms. Rojas ~ (Figure C1), the transport team education coordinator at Lurie Children's Hospital. The interview was scheduled for January 28 at 11:00 AM CST. Due to COVID-19 restrictions, the interview took place remotely via Zoom. One member of our team, Karthik Subramanian, was available for the interview, actively taking notes and asking questions alongside the other teams of Section 10. The rest of our team members watched the Zoom recording with Ms. Rojas's permission to record the interview for students who could not attend and those who would like to review information.

Figure C1: Zoom Interview with Ms. Rojas

III. Results

The results of our research are largely qualitative due to the nature of an interview. We noted several key takeaways, including:

1. The primary concern of the Transport Team is whether velcro would be secure enough to keep the infant from intensely moving in the isolette during a crash.
2. The targeted babies are under 1500 grams and fragile. The Transportle is required to position the infant's head midline, have some sort of respiratory support, either a breathing tube that's been inserted or assisting their own breathing with little prongs, and maintain the infant's homeostasis.
3. The general transportation process at Lurie Children's Hospital starts with a call from the referring hospital coming into the Communication Center. Due to strict guidelines as to age, size, and disease processes for infants, special care nurseries around the Chicago area refer to the Transport Team once they could no longer admit more infants. The Transport Team immediately joins the NICU with the referring physician to have a conversation about the baby. With information about the infant's age and weight, the team selects the appropriate temperature to keep the baby warm in the isolette. Once the

team gets all its supplies (IV pumps, ventilator) built into the isolette, they pack everything up in the ambulance and drive out (or fly if the infant is in severe condition or further away).

4. International Biomedical does marketing and the distribution for the Transportle, but Neonatologist Dr. Jane Scott developed it as well as the Tortle Head Support, an independent product that comes along with the Transportle. The Tortle is a device that holds a child's head at certain positions, typically midline. When a baby is young, if they constantly lay on their back, they get their head molds to a flat area on the back of their head. According to Ms. Rojas, "Damage in the brain is the most lifelong devastating injury that babies can suffer."
5. In the Transportle, the Transport Team is expected to have access to the infants' airway and room for IV treatments (intravenous). The team tries to pull everything out through the port, giving medication using extension tubes without actually going in the isolette. The infant's head is placed by the rear of the isolette, and IV tubings, blood pressure cuffs, pulse oximeters, and EKG leads are coming off the left side of the patient. So when the team puts the infant in the isolette, everything is in front of them and nothing gets caught behind.
6. The Transportle consists of:
    - A disposable docking station that sits in the isolette in place of the mattress that comes with it
    - A "Womba Pod," which serves as the continuation of the mother's womb
    - A wedge that mitigates the downward slope of the isolette to keep the infant's head elevated
    - Wider supplemental straps in addition to the thinner straps that come with the Transportle
    - Earmuff and sunglasses
    - The Tortle.

    The whole Transportle gets put on the mattress in NICU, which is reusable.

7. The wider supplemental straps were used by the team to secure infants 7-8 years ago. They stopped using them because the Illinois Department of Transportation or higher

regulatory body stated that velcro was not the most secure. In addition, velcro straps are made of cloth, and their strength decreases the more they are used. Therefore, they will be disposable while the rest of the system the team uses now is reusable.

8. The problem of the four-point restraint system that the team is using now is that it can't get around the Transportle. Thus, the two products are currently unoptimized when working together. There are no other alternative restraint solutions because it's a really confined space.
9. The goal of using the Transportle is for an infant to stay in the Womba for 72 hours up in the neonatal intensive care unit. It is a one-time-use product from the infection control standpoint.
10. If the Transportle fails to meet expectations, the backup solution would be abandoning the Transportle and go back to the existing harness.

IV. Discussion

1. The Transport Team requests our DTC section to investigate if there's any better way to secure infants on the Transportle so they feel confident having neonatal babies in the device. They ask for recommendations and different perspectives from us as to what we could augment the Transportle with.
2. The benefits of the Transportle include the developmental accessories that come with it, such as the head positioning aids and the straps wrapping around the lower extremities to keep the baby contained. The Transportle is also user friendly as the supplies preparing process could be done beforehand.
3. Ms. Rojas reassured us that safety is the biggest priority, and we shouldn't have to worry about the cost effectiveness of the product.

V. Conclusion

The interview with Ms. Rojas was a success and critical to our team in specifying the problem with the restraint system and perceiving the pros and cons of the Transportle's functions. Moving forward in our research, our focus would be brainstorming on different restraint systems that meet the satisfactions of the Transport Team. Some of the requirements include safety, secureness of the Transportle within inner tray, availability to other medical equipment, and ease to use. Our future research opportunities include sending two students from our section, Erin and Grant, to visit the Children's Hospital and observe the transport process, guided by Ms. Nally, the Transport Team Safety Coordinator. We expect that they will be able to take images of a detailed look at the Transportle and the isolette system, as well as bringing back a physical product for our section. We will also send out a short-answer survey to the entire Transport Team for additional complaints or praises they have about the product. Lastly, the Transport Team scheduled to put a trial in place on February 1 with the caveat that our DTC section would work alongside to access what we have currently and work to improve. With the above mentioned, our DTC group will gain a holistic understanding of what is expected of us after the researching phase, moving onto brainstorming and prototyping with greater confidence.

Appendix D: Project Definition

Constructing/Modifying Restraints for an Infant Transport Device to Improve the Safety of Neonatal Infants and Satisfy the Needs of the Transport Team

Client: Ms. Laura Westley, Ann & Robert H. Lurie Children's Hospital
Team members: Kevin Chen, Jake Gallardo, Karthik Subramanian, Winston Zhao
Date: 2/28/2021
Version: 3.0

I. Mission Statement

Our mission is to meet the needs of the medical staff, transport team, and parents by designing restraints that effectively secure the infant to the Transportle, are easy-to-use by the transport and medical teams, accommodate their medical equipment, and are long-lasting.

II. Project Deliverables

- Final Report & Poster
- Final Prototype
- Project Video: Presented during the DTC online fair

III. Constraints

- Budget: $100
- Due Date: March 16, 2021
- Most research must be conducted virtually (COVID-19)
- Tools and restrictions of the Ford shop

IV. Users and Stakeholders

- Transport Team and Medical Staff at Lurie Children's Hospital
- Neonatal & Critically-Ill Preterm Infants

- Parents of the Infants

V. Users Profile

The transport team at Lurie Children's Hospital is a crucial component of the quality medical care the hospital provides to its patients. This team encompasees first responders, EMTs, ambulance workers, and receiving hospital staff, as defined on the hospital's website [13; *Appendix A: Background Research Summary*]. They use a device called the Transportle to move newborn babies from one location to another. They engage in extremely time-sensitive tasks, dealing with critically ill infants, and have to traverse sizable stop-and-go traffic near downtown Chicago to fulfill their duties.

VI. Illustrative User Scenario

The following illustrative user scenario is adapted from the interviews of our project partner, Ms. Laura Westley, and the transport Team Education Coordinator, Ms. Tracy Rojas. They related to us the operations of the transport team at Lurie Children's Hospital, expressed their safety concerns with the velcro straps, detailed the benefits of the current device, and provided insight on their experiences with the Transportle and other mechanisms of securing the infant.

It has always been the transport team's priority to ensure the safety and health of its patients, including neonatal infants. This is why the team at Lurie Children's Hospital have invested so much time into landing a transportation device that provides maximum security to the baby. After many months of researching, interviewing partner hospitals across the nation, and investigating literature surrounding the topic, Lurie Children's Hospital fell upon a securement device (the Transportle) that seemed to meet the needs of the medical staff. Namely: the Transportle maintains warmth for the infant, comes with developmental accessories (e.g. Tortle -- which aids in stabilizing the head), and also accommodates other necessary medical equipment like respiratory support and IV tubes. In addition, Ms. Westley and Ms. Rojas affirm that the Transportle is an easy-to-use piece of equipment.

However, the team did not feel fully comfortable with the velcro straps (a material used by the hospital team seven to eight years ago) used to secure the infant. They were worried about the safety of the infant in the case of a serious ambulance crash. Youtube videos showing an infant doll, strapped in velcro, rocking and shaking immensely in simulated turbulence did not give ease to the staff. In the words of Ms. Rojas, they felt they were “going backwards” with the adoption of velcro. While there have not been serious ambulance crashes, there was one incident of a car rear-ending the ambulance. Thankfully, no one was injured then; but, as Ms. Rojas notes: “Just because nobody’s had any problem… doesn’t necessarily settle well with the [transport] team. We don’t want to be the first one that has any problems.”

For all the benefits that the Transportle offers, compromising on the most essential aspect of interfacility transports is a non-starter for the hospital. Thus, as the hospital begins initial testing of the Transportle, the only concern that preoccupies their minds is safety.

VII. Project requirements - Needs Identification, Metrics, and Specifications

Needs	Metric	Units	Ideal Value	Allowable Value	Measured Value
Provide Safety	Accelerometer: net distance in all 3 axes, net velocity in all 3 axes, net	Acceleration: m/s^2; Force: lbs	Acceleration: 0 in each axis; Force: Ideally able to	All levels of turbulence: 0.3 m/s^2[3] Force: 10 lbs[4]	Low (typical) Turbulence: 0.2 m/s^2 (within ISO guidelines)

[3] There are currently no agreed-upon standards for whole-body vibrations for neonates. However, there are guidelines for adults (ACGIH specifies 0.87 m/s^2 **[17]** for industrial workers. ISO defined 0.3-0.6 m/s^2 as "a little uncomfortable" **[18]**. Since studies show that lower weight infants experience harsher external frequencies than adults **[17]**, the largest allowable value for vibration (measured with a triaxial accelerometer) is 0.3 m/s^2.

[4] According to the SAE (Society of Automotive Engineers), “The force of a front impact at 30 mph was significant enough to cause the gurney to break free of the antlers, sending a restrained patient forward into the space often occupied by the captain's chair or jump seat in the patient compartment” **[19]**. Assuming this velocity is reached in 0.5 s, and the infant weighs 1.5 kg, the force in pounds needed to break the straps would be 9.04 lbs. Our team decided to round up to 10 lbs for extra security.

	acceleration in all 3 axes Force required to unlatch securements		withstand very large normal and shear forces		Moderate Turbulence: 0.5 m/s^2 High Turbulence: 0.8 m/s^2 (within ACGIH guidelines) Force: Indeterminate value, but held up to high turbulence
Secure Transportle onto Inner Tray	Acceleromete r: net change in distance in all 3 axes	(m, m/s, m/s^2)	0 in each axis	0.3 m/s^2	See Above Values for "Provides Safety"
Stabilize Infant Midline	Acceleromete r: net distance in all 3 axes, net velocity in all 3 axes, net acceleration in all 3 axes	(m, m/s, m/s^2)	0 in each axis	0.3 m/s^2	See Above Values for "Provides Safety"
Make Easy to Use	Taking less time, requiring less equipment, and needing fewer people, *Limits the need to reach over the infant*	Time: Seconds Number of people: Integer Reaching Over Infant: Number of Times spent reaching over	Time:half than average time pre-modificat ion (45.19 sec) # of People: 1 Reaching Over Infant: None	Time: same average time compared to pre-modificat ion (22.6 sec) # of People: 2 Reaching Over Infant: Two times, with no physical contact	Time: 21.57 sec # of People: 1 Reaching Over Infant: -When Installing: 1 -In Between Transports: 0

Accommodate Medical Equipment	Boolean	Yes or No	Yes (All medical equipment is unobstructed)	Yes (medical equipment has same level of obstruction as with previous design)	Yes (New straps are in same position, width of new straps are smaller than old design)
Fit within Isolette	Maximum isolette dimensions	$inches^3$	23” x 14.5” x 11.5”	23” x 14.5” x 11.5”	Yes (See above)
Have Reasonable Weight	Maximum Weight Capacity of Transport Vehicles	lbs	1 lb (something extremely light)	Same weight as previous straps	Slightly heavier, but offers increased safety.

Table D1: Needs & Requirements

VIII. Citations

[17] I. Goswami, S. Redpath, R. G. Langlois, J. R. Green, K. S. Lee, and H. E. A. Whyte, “Whole-body vibration in neonatal transport: a review of current knowledge and future research challenges,” *Early Human Development*, 06-May-2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0378378220302139#:~:text=Whole%2Dbody%20vibration%20during%20neonatal,acceptable%20vibration%20levels%20in%20adults.&text=Sophisticated%20engineering%20modifications%20to%20the,safety%20checks%20may%20be%20useful. [Accessed: 15-Feb-2021].

[18] J.-C. Bouchut, E. V. Lancker, V. Chritin, and P.-Y. Gueugniaud, “Physical Stressors during Neonatal Transport: Helicopter Compared with Ground Ambulance,” *Air Medical Journal*, 04-May-2011. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1067991X10003482#bib10. [Accessed: 15-Feb-2021].

[19] S. Renga, “SAE Standards for ambulance safety,” *EMS1*, 30-Mar-2016. [Online]. Available: https://www.ems1.com/ems-products/patient-handling/articles/sae-standards-for-ambulance-safety-YO3HhCYG7ViIGVEA/. [Accessed: 07-Mar-2021].

Appendix E: User Feedback Summary

I. Introduction

Through our previous interviews with project partners like Laura Westley and meetings with our shop specialist, Heidi Huckabay, we collected feedback regarding the details of the project and used that information to kickstart the creation of our solutions. Thus, during those interactions, we concretely established the problems that we need to address. These include securing the Womba Pod within the inner tray, minimizing unnecessary contact with the infant, and improving the current restraint system. At this point, we were ready to present our mockups that approximated our final designs to Ms. Rojas and Ms. Nally, senior members of the transport team. In the following report, we will discuss the feedback from this interview that will lead us into the final phases of our design process.

II. Methodology

Our interviews with Ms. Rojas and Ms. Nally were conducted during two separate sessions. Ms. Rojas' was scheduled for February 17 at 5:00 PM CST during class. Ms. Nally's session was initially going to be held concurrently in class but had to be rescheduled for the following day at 11:00 AM. Team members Karthik Subramanian and Winston Zhao prepared materials to present to Ms. Rojas while Jake Gallardo and Kevin Chen prepared a presentation and a physical mockup to demonstrate our ideas to Ms. Nally. The members present during Ms. Rojas' interview actively took notes while Karthik Subramanian presented our mockups, though only Jake Gallardo was available to meet with Ms. Nally. The mockups presented were, in no particular order: snap button attachments, an inner latching mechanism, a lateral strap/blanket, and a X-Strap restraint. The interviewees provided suggestions for which designs to pursue and which to scrap due to infeasibility or impracticability. User feedback was recorded, and the results of the interviews will be presented below.

III. Figures

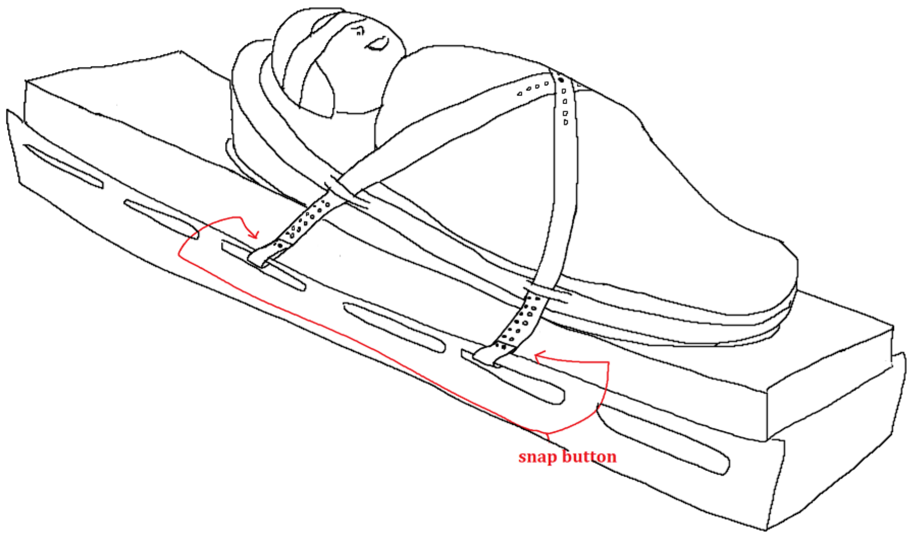


Figure E1: Snap-Button Restraint System

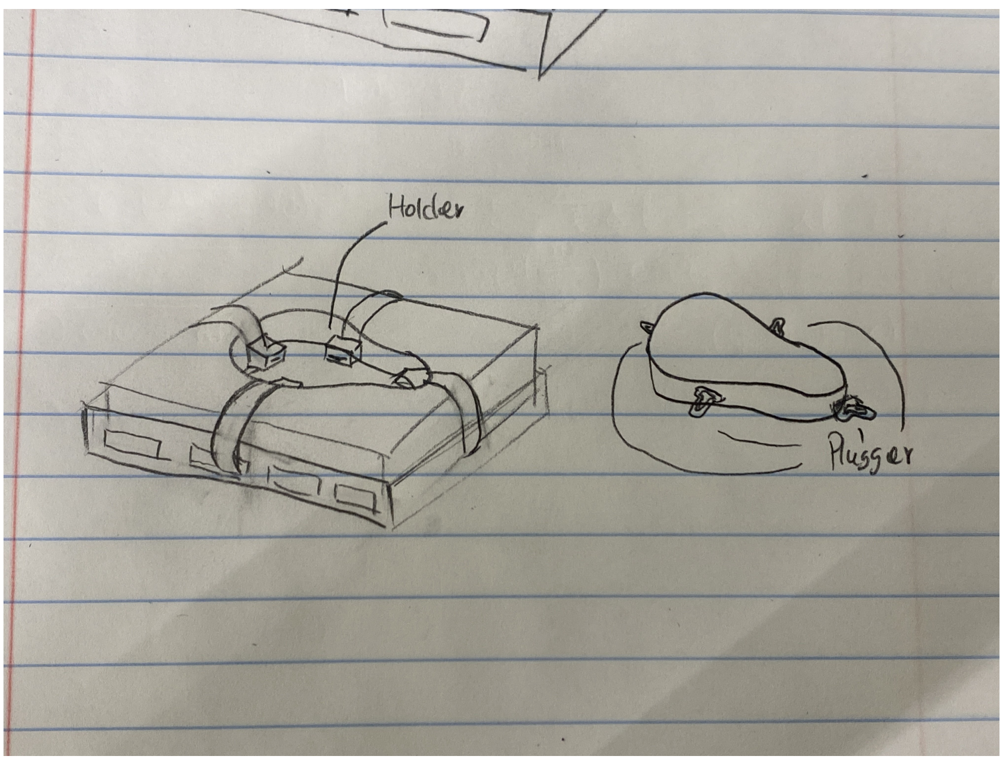


Figure E2: Inner Latching Mechanism

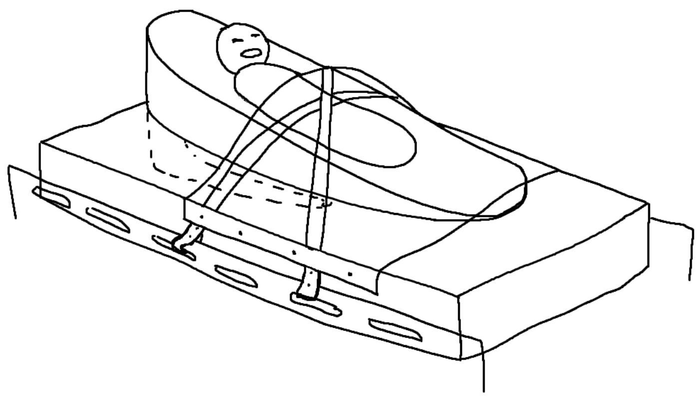


Figure E3: Lateral Strap/Blanket

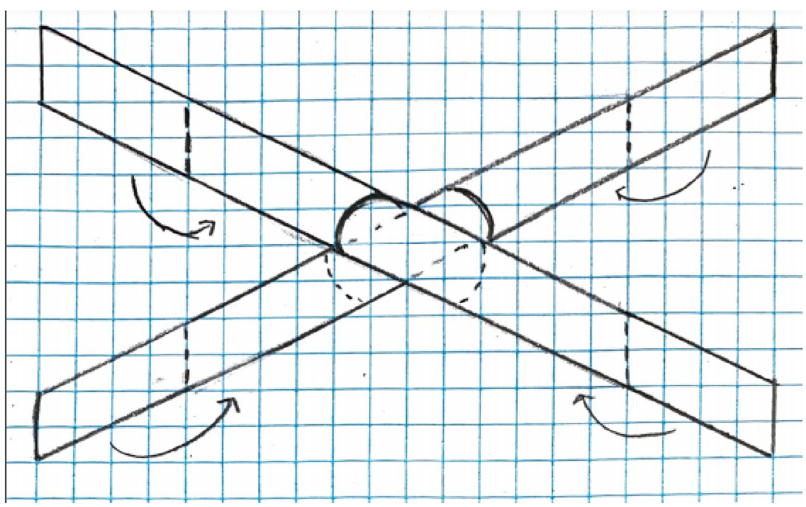


Figure E4: X-Strap Mockup

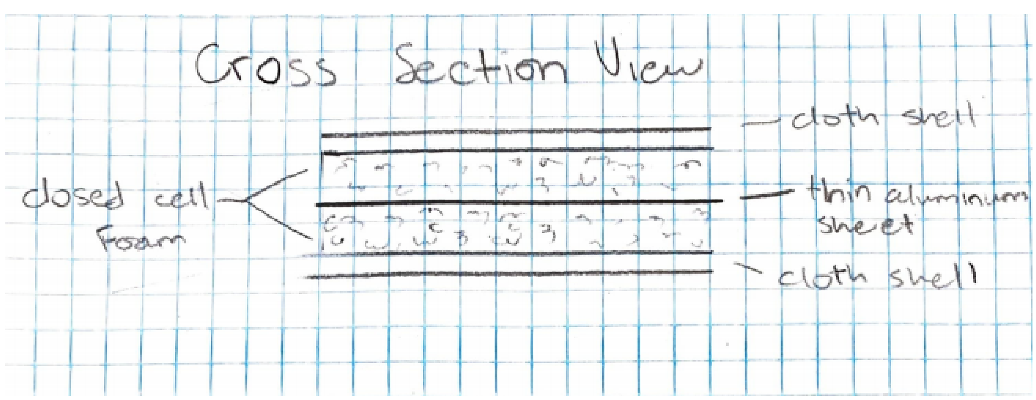


Figure E5: X-Strap Composition

IV. Results

For simplicity's sake, the following results have been divided into two sections, one for each interview. Here are the takeaways.

<u>Ms. Rojas' suggestions:</u>

1. One of her main recommendations was to physicalize our designs for future presentations because it would lead to easier evaluation. Moreover, any approved ideas would also need to be physically constructed as required for testing.
2. Ms. Rojas reiterated the transport team's disapproval of velcro. Thus, when we presented the alternative of using Snap Buttons ~ (Figure E1) ~ as a securement method, she supported the idea. She elaborated that velcro straps easily get stuck to other components of the Transportle and that they are not reusable. It was specifically stated that snap buttons appeared to be relatively easier to use and would not impede the process of strapping in the infant.
3. She was also intrigued by the idea of a latching mechanism ~ (Figure E2). However, she added that all the components of the Transportle already fit snugly within the isolette. However, she emphasized that this proposal would not be intrusive or hamper the Transportle's ease of use because it does not attach to points where external equipment may be used.
4. The lateral strap/blanket ~(Figure E3) ~ seemed like a reasonable option to replace the two extra straps used to attach the Transportle to the isolette tray. However, Ms. Rojas did not provide any feedback concerning this design.
5. We also proposed the X-Strap ~ (Figure E4) ~ design which leverages a patented device called the Sam Splint to create a rigid yet malleable restraint system. The thin aluminum sheet and closed cell foam ~ (Figure E5) ~ are what make up the splint. Ms. Rojas explained that the Sam Split and X-Strap were appealing because it would reduce the need to reach over the Transportle during securement, curtailing potentially dangerous contact with the infant.

Ms. Nally's suggestions:

1. Ms. Nally was also very supportive of introducing snap buttons as a replacement for velcro. She specifically stated that her team would appreciate the snapping points being located at the sides of the Transportle, making it much safer to use than midline attaching velcro.
2. She also suggested that only one end should contain snap buttons, so all necessary adjustments can be made from the opening of the isolette.
3. Ms. Nally cleared up any safety concerns regarding the hard metallic substances in our design, as there shouldn't be any issues because the Transportle helmet also contains such buttons.
4. However, she almost immediately shot down the idea of an inner latching mechanism as the transport team are still looking for a set of modified straps. The purpose of these straps are to restrain and keep the infant stable and comfortable during the ambulance ride. A latch mechanism does not provide these benefits for the baby as it only functions to attach the Transportle to the docking tray.
5. Ms. Nally had concerns regarding the blanket/lateral strap. She elaborated that its structure impedes access to IV tubing near the stomach, which is a necessity for some infants being transported. These flaws prevent this mockup from being a contender for our final design.
6. In the last segment, she expressed that the X-Strap was an idea worth looking into and should be a solution we pursue. However, Ms. Nally reiterated that having a physical model of the X-Strap and Sam Splint to observe how it's structure interacts with the Transportle would be essential to validate the use of this restraint. In the future, a functional prototype would also be required for testing purposes.

V. Discussion

1. Many of Ms. Nally's recommendations aligned with those of Ms. Rojas's. However, there are some differences in feedback that are worth discussing. These distinctions may be in part due to our different interviewers and presentations.

2. We had not prepared a handheld mockup for the Ms. Rojas interview as Jake Gallardo was presenting a mockup of the X-Straps to Ms. Nally. Thus, this may have been a source of confusion and may have led to some conflicting feedback from the sources.
3. From Ms. Rojas' feedback, we extrapolated that this latch attaching the Womba Pod to the inner tray may be an unnecessary addition to the system as a whole. Moreover, Ms. Nally strongly suggested avoiding the inner latching mechanism as the transport team are still looking for a set of modified straps.
4. We also concluded that the blanket/lateral strap would be impractical for usage, even though it was a workable solution for securing the baby and Transportle, as the fabric would obstruct any medical equipment or tubing attaching to the infant's chest or abdomen. Ms. Nally entirely agreed with Ms. Rojas regarding the blanket/lateral strap. IV tubing, blood pressure cuffs, pulse oximeters, and EKG leads would be obstructed by the blanket. We have concluded that this idea should be dropped.
5. Ms. Nally concurred with Ms. Rojas regarding the X-Strap made of padded Sam Split. This proposed solution appears to be strongly viable, as it is composed of a rigid but malleable material that can safely restrain infants while also dramatically reducing the need to reach over the baby and make unnecessary contact. In terms of future objectives, we are currently in the process of purchasing these materials to construct this design.

VI. Conclusion

In short, our interviews with Ms. Rojas and Ms. Nally were extremely beneficial and proved to be essential in helping narrow our concepts and lead us to practical and actionable solutions to the problem at hand. The feedback received from multiple interview sessions have allowed our team to gain a comprehensive understanding of our project. Thus, as we move forward with the creation of our final designs, we will take the following into account: a need to stay within the domain of straps, allowing easy access to the child when restrained, minimizing reach over when securing the baby, and accommodating all medical equipment current in use by the transport team. This will prove useful as our team spends more time in the shop in coming weeks to begin constructing our prototypes. In addition, we plan to supplement our required DTC shop training with formal mill and lathe training that should improve the quality and expand the possibilities of our products. Armed with these new skills and the knowledge from our many interviews, our team is sufficiently prepared to proceed into the final stretch of this project.

Appendix F: Bill of Materials

Item	Description	Qty	Source	Unit Cost
Sam Splint (36”)	Aluminum Sheet Padded with Closed Cell Foam	1	Amazon	$10.00
Snap Buttons (8mm and 10mm, studs and sockets) ~ 120 sets	Interlocking Snap buttons used to latch materials together	1	Amazon	$6.99
Water-Repellent Cotton Fabric Sheet ~ 5ft	A soft, water-repellent fabric material used to cover the Sam Splint	2	McMaster-Carr	$11.50
Duct Tape ~ 60’ Long, 0.5” wide; Silver	Strip of cotton/polyethylene plastic Adhesive	1	McMaster-Carr	$3.54

Table F1: Bill of Materials

Total Cost: $32.03

Appendix G: Instructions for Construction

Tools

- Thread & Needle
- Sewing Machine
- Scissors
- 6” Box Cutter
- Cutting Mat
- 0.125” Rivet Hole Metal Punch

Materials

* See *Appendix I: Bill of Materials*

Step 1: Strap Preparation

1) Using the box cutter, cut two 30” by 1” Sam Splint straps on the cutting mat.
2) Cut four 30” by 0.25” and four 1” by 0.25” strips of duct tape. (Note: If there is not enough duct tape lengthwise for this, segments of tape that add to 30” will suffice).
3) Apply the longer duct tape to the sides of the cut straps and the shorter duct tape to the ends of the strap - where there is exposed aluminum.

Step 2: Cloth Preparation & Application

1) Using the Box Cutter, cut two 32” by 3” sheets of Water-repellent Cloth Fabric used to cover the straps. (Note: These dimensions are too large for the straps; however, all excess cloth will be discarded eventually).

2) Fold each sheet in half lengthwise, resulting in two 30” by 1.5” double-layer sheets.

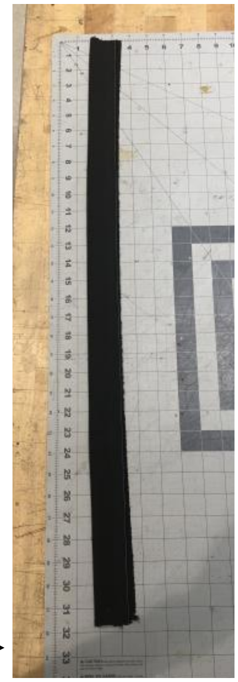


Figure G1: Unfolded Cloth (30” by 3”)

Figure G2: Folded Cloth (30” by 1.5”)

3) Measure 0.25” from the open edge on the short side and mark this spot.

Figure G3: Marking 0.25” from the Open Edge of the Folded Cloth

4) Using the Sewing Machine, sew the folded cloth along the line of the marked spot, parallel to the length. This will create a sleeve for the strap. (Note: Ignore the excess material for now).

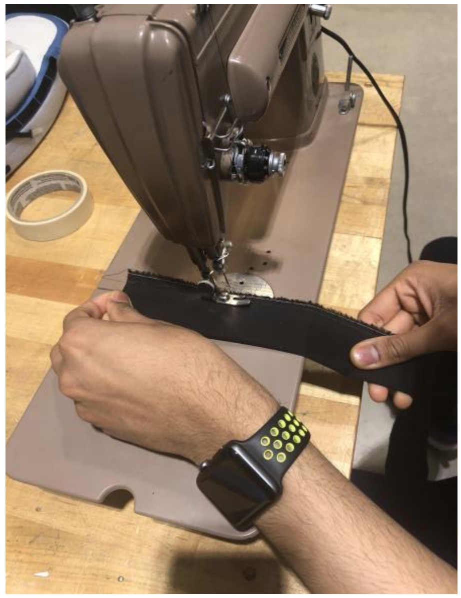


Figure G4: Sewing the Folded Cloth along the Marked Line

5) Slide in the SAM splint straps into the sewn loops of fabric such that there is exactly 1" of excess fabric at either end of the strap.

Figure G5: Sliding the Strap into the Sleeve

Figure G6: 1" of Excess Fabric on the End

6) Tightly pinch and pin this excess fabric at the edge of the strap.
7) Using the Sewing Machine, sew together these ends such that the fabric perfectly covers the SAM splint on all sides.

Figure G7: Stitching the End of the Strap

8) Using the box cutter, cut off all excess fabric at the ends and sides. WARNING: Do not cut through the stitches as it will create a hole in the fabric and expose the strap.

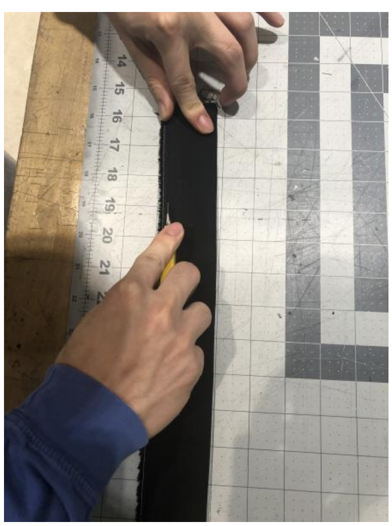


Figure G8: Cutting off All Excess Fabric ***Figure G9: Result of Cutting Excess Fabric***

9) For both straps, use the rivet punch to punch 0.125" holes in the following places:
   a) 2 Holes: 0.25" from the end of the strap and 0.25" from each respective edge of the strap.
   b) Starting 3" away from the holes in part (a), start punching pairs holes along the lines of the original holes, leaving 1" in between each set of 2 holes. (There should be 4 of these pairs in total).
   c) At the center (18" away from the end of the strap), punch one hole in the middle widthwise.
   d) Punch two more holes on either side of and 1" apart from the center hole.

Figure G10: Punching Holes Through Strap

Figure G11: Result of Punching Holes

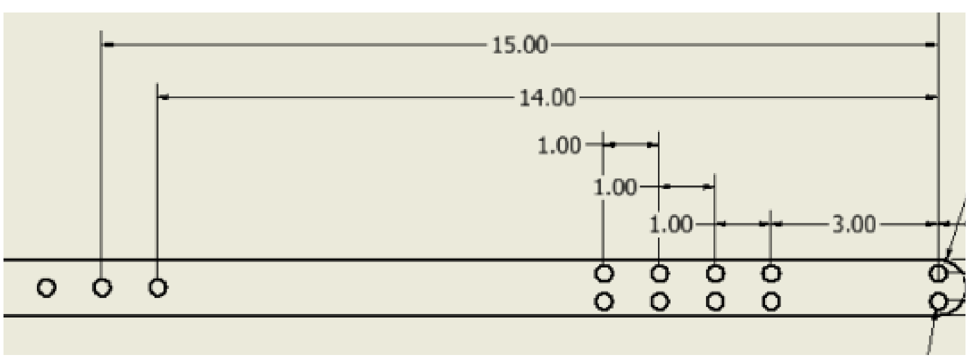


Figure G12: Locations of Holes on the Strap

Step 3: Snap Button Application

1) Using thread and a needle, hand sew 2 studs 0.25” from the end of the strap and 0.25” from each respective edge of the strap.

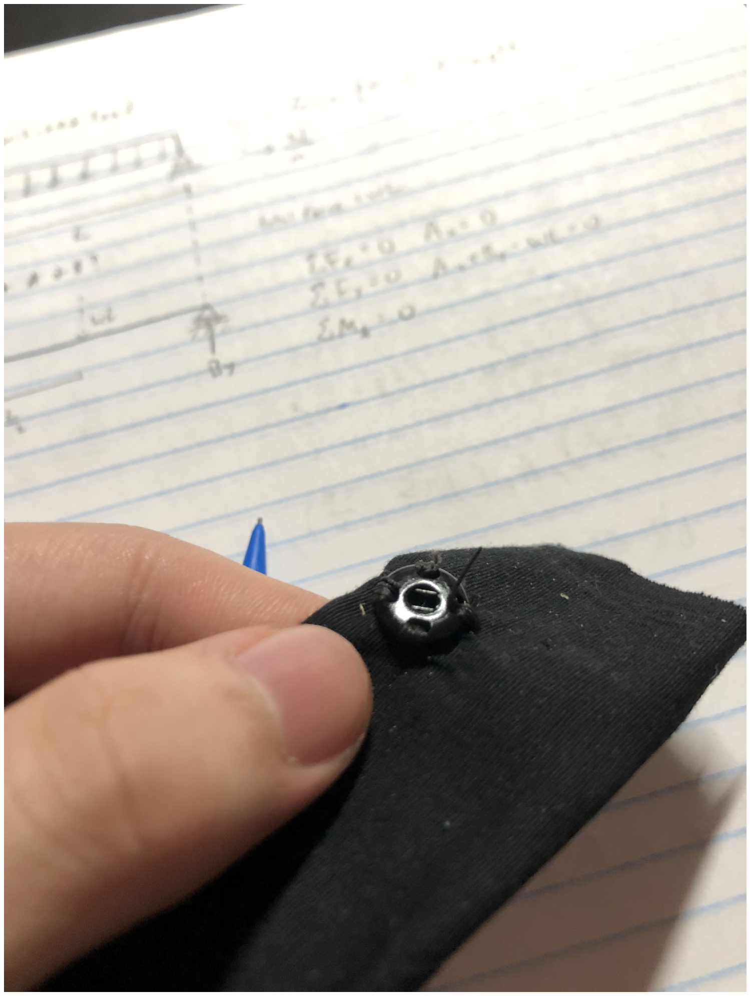


Figure G13: Snap Button Sewed to Strap

2) Starting 3” away, sew sockets in the same orientation, leaving 1” in between each set of 2 sockets.
3) Repeat 3 more times. There should be 2 studs and 8 sockets on this side of the strap.

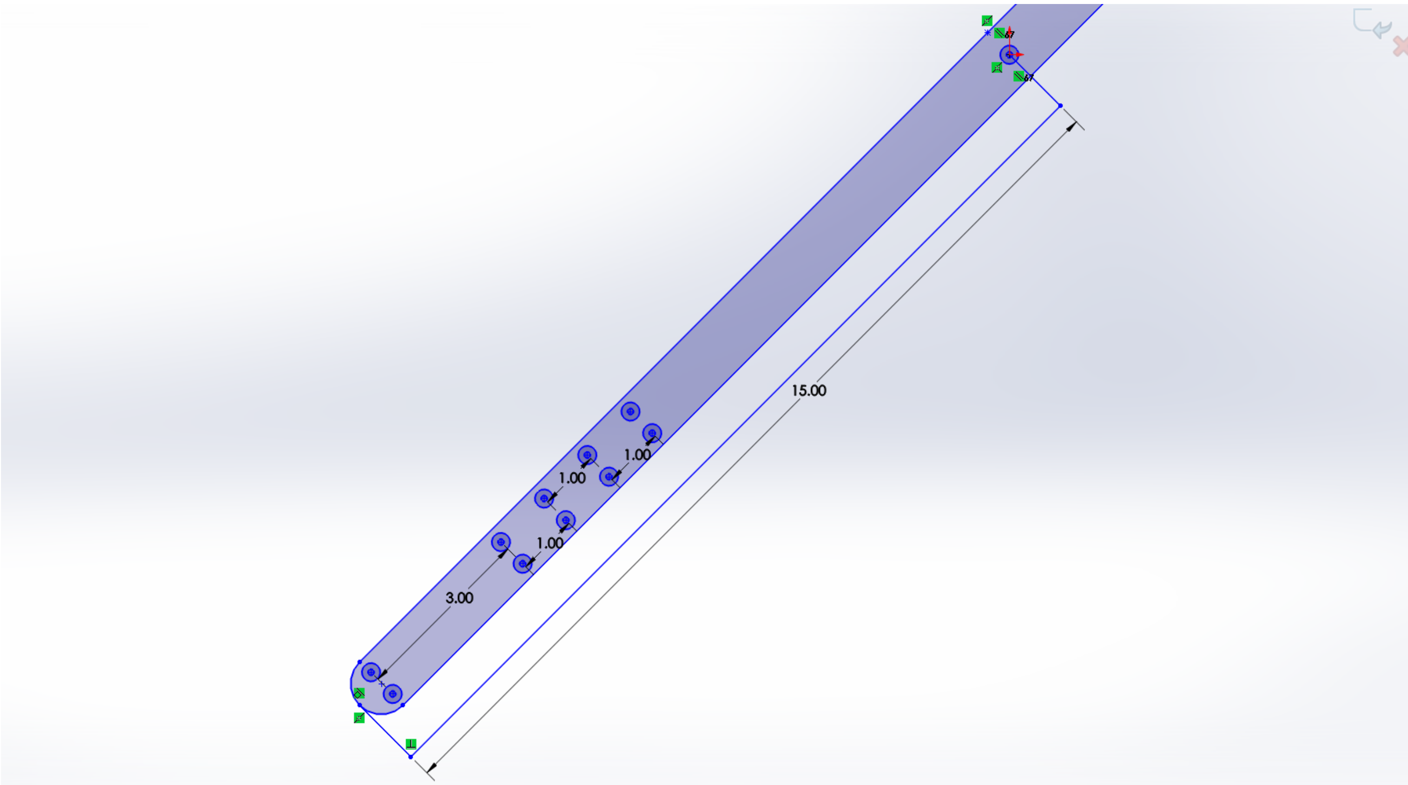


Figure G14: Locations of Studs and Sockets on Ends of Strap

4) On the side of the strap located at the back of the isolette, only sew one set of sockets as the adjustment points should only be at the opening of the isolette.
5) Both straps will attach at their midpoints to form the X-shape. Thus, sew a stud on one and a socket on the other for attachment.
6) Sew 2 more sockets onto the strap with a socket in the middle

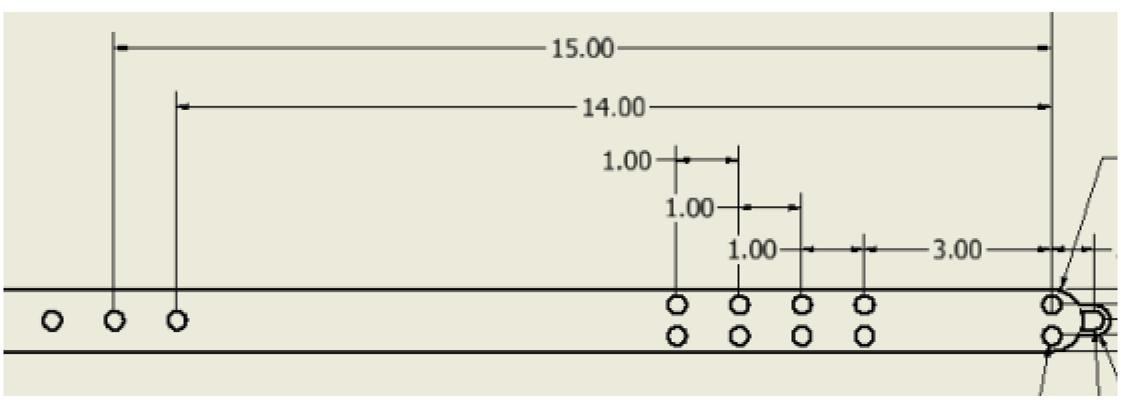


Figure G15: Locations of Studs and Sockets on Entire Strap

7) (Information for *Appendix H: Instructions for Use*) The strap with the stud at its center will be referred to as the downward-facing strap. The strap with the socket at its center will be referred to as the upward-facing strap.

Step 4: Pull Tab Application

1) Using the same method of sewing the cloth's ends shut, loop 2 pieces of thin rectangular velcro found within the stock Transportle velcro package and sew the ends of the loop.
2) Repeat the sew in the other direction, fully attaching the velcro onto the strap to provide an easier way to detach snap buttons and possibly stick to the ceiling of the isolette.

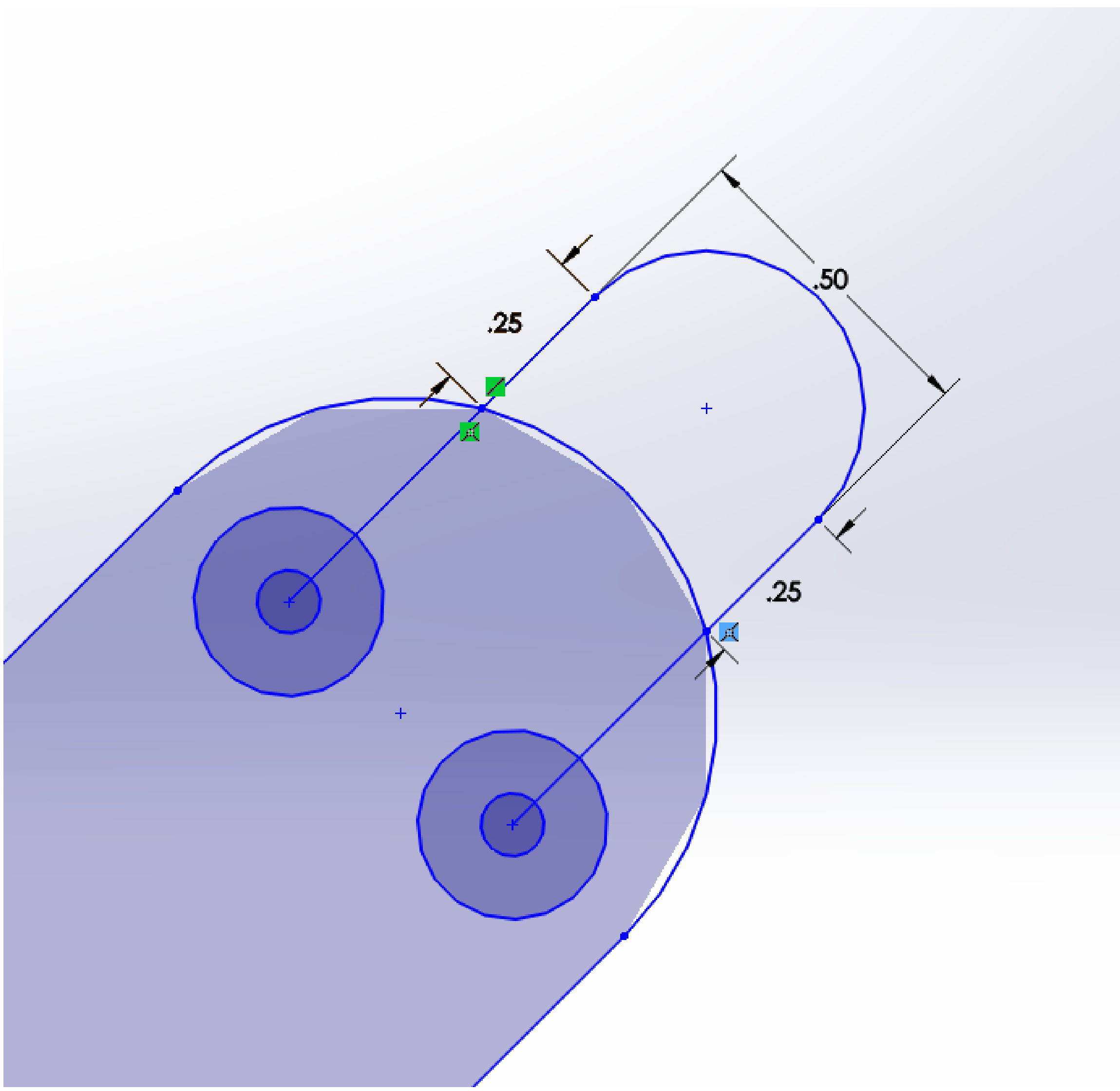


Figure G16: Pull Tab Location and Dimensions

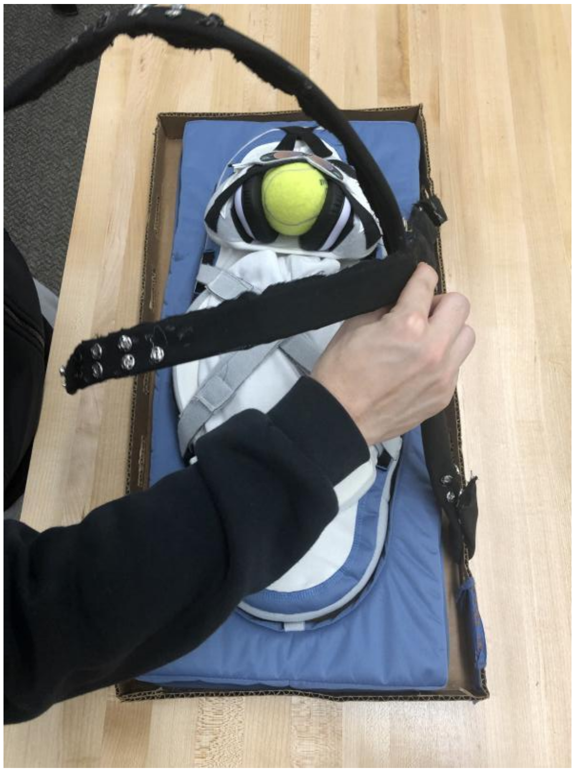
Appendix H: Instructions for Use

Initial Set-up:

1) Designate one end of each strap as the back tail. For the upward-facing strap, loop the back tail through the first, back isolette slot. For the downward-facing strap, loop the back tail through the fifth, back isolette slot.
2) Latch the Snap Button Stud pair on each strap to a corresponding socket pair to secure the back tails.
3) Latch together a center stud and socket to connect the two straps at the intersection.

Figure H1: Result of Steps 1-3

4) Grip the intersection of the straps with two fingers on the top and a thumb on the bottom.
5) Rotate this intersection point away from you such that the front tails of the strap move upwards. Continue doing this until the straps have moved a comfortable distance upwards that allows the Womba Pod to be inserted into the tray of the isolette. (Note: It may be necessary to fold the front tail over each other to allow the straps to remain freestanding)



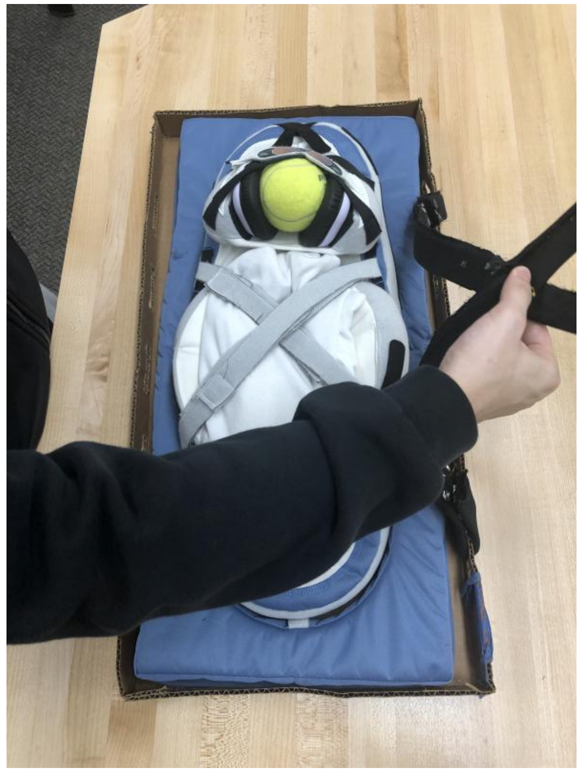


Figure H2: Gripping the Intersection

Figure H3: Rotating Intersection Away

Strapping the Infant:

1) Prepare the Docking Station and Womba Pod with the infant as normally would be performed.
2) Insert the Docking Station and Womba Pod onto the Inner tray of the isolette.
3) Hold each front tail of the freestanding strap with each hand.
4) Pull the straps downward to cover the infant and Transportle.

Figure H4: Holding Freestanding Tails *Figure H5: Pulling Down the Strap*

5) Just like the back tails, loop the front tails of each strap through the front isolette slots. For the upward facing strap, the front tail will loop through the fifth, front isolette slot. For the downward-facing strap, the front tail will loop through the first, front isolette slot.
6) Latch the Snap Button Stud pair on each strap to a corresponding socket pair to secure the front tails.

Figure H6: Latching the Snap Buttons

7) Press down the straps at the edge of the Womba Pod.

Figure H7: Pressing Down the Straps

8) OPTIONAL: Readjust the center snap buttons so that the center of the 'X' shape aligns with the midline of the neonate.

In between Transports:

1) Very similar to the initial set up, unlatch the front tails of the straps and take out these ends from the isolette slots.
2) Grip the intersection of the strap and rotate it away from you such that the front tails of the strap move upwards.
3) Remove the Womba Pod with the infant from the tray of the isolette. Let the straps remain freestanding until the next transport.

Cleaning Process:

1) Clean the straps (the outer water-repellent cotton fabric) with soap and water to sanitize between each session of usage. (Note: these straps are not suitable for washing machines).

Appendix I: Shop Consultations

I. Introduction

As part of our rigorous and thorough research and prototyping process, our team scheduled two in-person shop consultations with Heidi Huckaby. In our first meeting, the focus was toward understanding the project definition, interacting with a physical Transportle, and initial ideation of amendments that could be made. In our second meeting, we centered our discussion around the initial mockup ideas our team brainstormed: feedback on said mockups, how these mockups can be constructed, and methods for testing the prototypes. Below are the major takeaways from each of the meetings.

II. Shop Consultation #1

Date & Time: February 5, 2021, 5:00 PM - 6:00 PM

Location: Ford Building

Team Members Present: Kevin Chen, Jake Gallardo, Karthik Subramanian, Winston Zhao

Takeaways:

1) Project definition: Not only must the infant be secured to the Transportle, but the Transportle should be properly secured to the isolette. The entire design must also be easy-to-use. Though these ideas had arisen after Ms. Rojas' interview, the shop consultation solidified this definition.

2) Shortcomings of Transportle

- **a)** The outer velcro straps were unnecessarily complicated to install, as they arrived in four separate pieces and easily tangled on each other
- **b)** The Womba Pod of the Transportle was visibly detached from the docking station.
- **c)** The straps were inefficiently looped through the side of the Womba Pod. Instead of utilizing the inner straps to fasten the Transportle to the Isolette, an outer (complicated) pair of straps were required.

3) Preliminary Testing:

- **a)** Video: Simulated Turbulence

   b) Analysis: Though this test did not properly simulate turbulence, and was not conducted in a controlled manner, there is concern with the amount of shaking experienced by the baby doll.

4) Brainstorm:
   a) A single strap can be used to fasten the infant as well as the Transportle to the isolette
   b) An inner latching mechanism can be utilized to fasten the Womba Pod onto the Docking Station

III. Shop Consultation #2

Date & Time: February 19, 2021, 5:00 PM - 6:00 PM

Location: Ford Building

Team Members Present: Karthik Subramanian, Winston Zhao

Takeaways:

1) Many lingering questions about our initial design, such as the efficacy of building and testing the mockup, depended on materializing our ideas

2) The materials for our initial ideas (Sam Splint and Snap Buttons) were ordered

3) Performance tests were brainstormed:
   a) The accelerometer in the iPhone could be used to test turbulence
   b) Stress tests for both the velcro and snap buttons should be performed

Appendix J: Design Review Summary

I. Introduction

Our team presented our design review via Zoom on February 25, 2021. Team members Kevin Chen, Karthik Subramanian, and Winston Zhao were present to convey and yield feedback about our design ~ (Figure E1; *Appendix E: User Feedback Summary*). Three features of our current design were presented: The X-strap, Snap Buttons, and Sam Splint.

The X-Strap ~ (Figure J1) ~ was described to be a continuous, single strap that limited the need to reach over the infants as often. Therefore, utilizing this modification would aid in overall ease-of-use. Then, Snap buttons ~ (Figure J2) ~ were introduced as a replacement to velcro. Snap buttons were easier to use, less complicated, and more sturdy than velcro. Finally, Sam Splint ~ (Figure E5; *Appendix E: User Feedback Summary*) ~ was pitched as a rigid yet flexible material that would not only aid in the safety of the infant, but also be able to remain freestanding when unused. The Closed Cell foam that pads the aluminum sheet in Sam Splint provides extra cushion and also demonstrates great tensile strength.

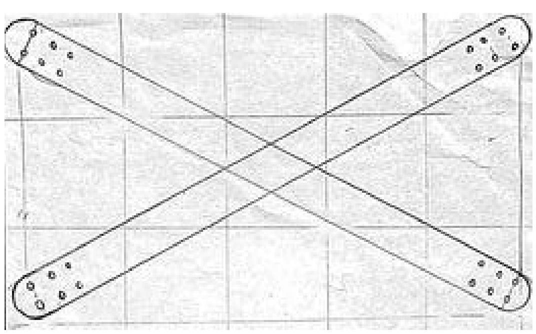


Figure J1: X-Strap

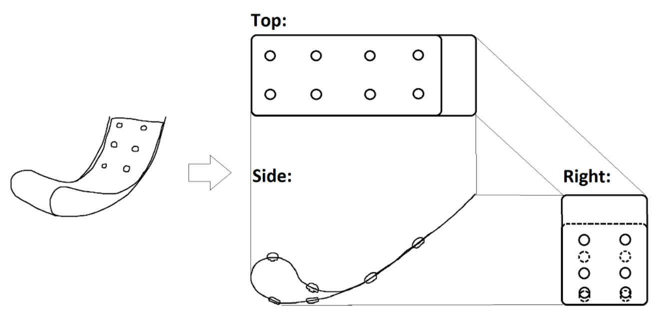


Figure J2: Snap Buttons

II. Summary of Feedback

Our team was able to procure valuable feedback from our peers. There were many design features that resonated with them, such as the adjustability of Sam Splint and the apparent ease of use of the single X-Strap. Validating these ideas were refreshing and necessary as we look to incorporate these into our prototype.

There were, however, multiple concerns pitched by our peers that allows us to investigate potential holes in our design. First, many pointed out that the composition of Sam Splint was rather dense and potentially too thick. They recognized that implementing straps that were excessively thick or dense could lead to problems such as: inability to attach snap buttons, irritation of the infant's skin to due to heat and pressure, added complexity of a bulkier strap, or inability to remain freestanding. Second, others voiced their concerns with Snap Buttons, unsure whether Snap Buttons were faster to use than velcro or whether Snap Buttons could withstand shear forces or other forces at various angles. Pertaining to the single, continuous strap, there was minor worry that adjusting it might be too tight for the infant. Finally, regarding Sam Splint, few wondered if its efficacy to remold into various shapes tapers off after a few uses.

Our peers also suggested a couple performance tests to verify or refute some of these concerns. One idea involves pulling the snap buttons at various angles to determine how well the buttons stick together. A second idea tests the Sam Splint through multiple cycles of use to observe how well it holds up.

III. Future Action Plan

A majority of the feedback consists of *potential* concerns with the idea, things to be mindful of when physicalizing the prototype. Thus, a lot of fixes and worries must be evaluated through rigorous performance testing, including those suggested by our peers. For example, only once our team can successfully prototype the straps can the issue to thickness be confronted. Only through educated trial and error can a perfect ratio of foam to Sam Splint be attained. This is true for the efficacy of snap buttons; it is pertinent to judge its strength once the model has been physically tested. And, if the single strap is indeed too tight, it may be necessary to use two straps conjoined at a center point with a snap button.

Apart from the unknown elements, there are few changes that can be incorporated now. For one, the outer material can be made out of nylon cloth such as not to be irritating to the infant's skin when strapped. Then, in order to release trapped heat, holes can be placed in the closed cell foam to emulate the features of open cell foam. In addition, adding outward facing material dedicated to the detachment of the snap buttons would aid in the straps' ease of use.

Appendix K: Performance Testing

I. Introduction

Performance testing was a crucial step to both validate the fears of the medical staff at Lurie Children's hospital, as well as validate or amend our proposed design. After buying certain materials needed to build the prototype and building a working mockup, our team conducted tests on the device to determine if the layed-out needs were met. Performance testing was conducted in the Ford building, on Friday, February 26 from 5:00 - 6:00 PM. Team members Karthik Subramanian and Winston Zhao were present.

II. Tests

*Each test requires the Transportle and isolette to be prepared with a doll: once with the current restraints (as the control group) and once with the modified restraints (the experimental group).

1) **Efficiency Test:**
   a) Control Group: Velcro
   b) Experimental Group: Snap Buttons
   c) Methodology: Both types of restraints were prepared as quickly as possible by one team member, while the others timed the process. Three trials per system were conducted, and the average time was computed.
2) **Securement Test**:
   a) Control Group: Current restraints
   b) Experimental Group: Single 'X-Shaped' Restraint
   c) Methodology: The isolette underwent a series of mock turbulence tests, with increasing turbulence provided for each test. The turbulence of the baby doll was measured using the accelerometer built into iPhone X.
3) **Stress Test:**
   a) Control Group: Velcro
   b) Experiment Group: Snap Buttons
   c) Methodology:

i) The straps were latched and unlatched to determine how many times the material can be used. If a material broke or was unable to relatch, it would be considered damaged.

ii) The straps were pulled at various angles to determine if shear forces could undo the straps

4) **Reusability Test**:

a) Control Group: Current Restraints

b) Experimental Group: Sam Splint

c) Methodology: The doll was secured using the restraints and then undone. This was repeated several times to determine if multiple previous uses of the restraints affected current performance

III. Results

Efficiency Test:

	Trial 1	Trial 2	Trial 3	Average Time to Secure
Velcro	40.98	55.05	39.54	45.19
Snap Buttons	23.56	22.60	18.56	21.57

Table K1: Results of Efficiency Test

*All times are in seconds

Securement Test:

Low Turbulence: 0.3 m/s^2 (safe, threshold value)

Moderate Turbulence: 0.6 m/s^2 (a little uncomfortable)

High Turbulence: 0.9 m/s^2 (acceleration of ambulance car rides)

*Above values adapted from **[17**; *Appendix D: Project Definition*] and **[20]**

	Low Turbulence	Moderate Turbulence	High Turbulence
Velcro	0.2 m/s^2 Range: ± 0.2 m/s^2	0.5 m/s^2 Range: ± 0.3 m/s^2	1 m/s^2 Range: ± 0.5 m/s^2
Snap Buttons	0.2 m/s^2 Range: ± 0.2 m/s^2	0.4 m/s^2 Range: ± 0.4 m/s^2	0.8 m/s^2 Range: ± 0.5 m/s^2

Table K2: Results of Securement Test

*The mode of observed accelerations was recorded. Outliers were ignored.

*There is great room for error (as denoted by the Range) in the measurements due to imprecise equipment and biased trials.

Stress Test:

	Normal Force	Shear Force
Velcro	Pass	Pass
Snap Buttons	Pass	Pass

Table K3: Results of Stress Test

*Note: Our team was unable to obtain accurate force measurements for each securement system. Instead, we decided to award each strap a "Pass" or "Fail" for their ability to withstand high turbulence from the securement test.

Reusability Test:

Cycle: The process of setting up the Transportle, securing the baby, transporting the baby, and unsecuring the infant.

- Sam Splint was successfully able to be remolded to the user's desire after multiple cycles (25 cycles were tested).
- Sam Splint was able to maintain its rigidity through multiple cycles
- After multiple cycles, regions with higher usage formed local creases that could not be undone. This did not affect Sam Splint's overall malleability.

- Therefore, the Sam Splint PASSED the Reusability Test

Other observations:

- The Sam Splint was unable to remain propped up and folded under its own weight *in certain positions*. Other times the Sam Splint *was* able to stay up+right.
- The Sam Splint (without an external nylon cloth) is 0.25” thick. This thickness is comparable to the current velcro straps.
- The center could become misaligned with excess adjustments.

IV. Discussion

From the Efficiency Test ~ (Table K1), it was conclusively determined that snap buttons took much less time to secure than velcro. This is very reassuring of the need to switch out of velcro and to snap buttons, as it saves nearly twice as much time.

From the Securement Test ~ (Table K2), the relative differences between the allowed turbulences of both restraints remains statistically insignificant, though the Sam Splint did fare marginally better in this particular simulation. When comparing the mode values of each restraint, the Sam Splint was able to stay within the adult turbulence threshold of 0.87 m/s^2, while the Veclro exceeded this. Both straps were able to stay within the ISO guidelines of “a little uncomfortable” (0.6 m/s^2) with low and moderate turbulences. Still, because of the wide variance of results observed, this notion cannot be taken as completely accurate. Despite this, the Securement Test did confirm that the Sam Splint restraints can match the current straps; and, due to Sam Splint’s rigid yet flexible nature, there is intuition behind the slightly lower acceleration values recorded.

From the Stress Test ~ (Table K3), it was determined that Snap Buttons were able to withstand shear and normal forces comparable to velcro. This instills great confidence that snap buttons, the more convenient and intuitive securement mechanism, are safer and more secure to use than velcro. In fact, the internal strength of the snap buttons is so large that the attachment point between the button and foam on the Sam Splint is weak. Therefore, it is pertinent to sew the buttons on the foam. We plan to accomplish this with the addition of a nylon cloth to help cover the Sam Splint strap and prevent any injury to the infant. This cloth will extend slightly longer than the sand splint to provide an area with negative space where snap buttons can be sewed or punched in.

From the Reusability Test, it was found that Sam Splint was able to be remolded and remain rigid for multiple cycles. In addition, the local creases sustained after multiple uses did not affect the usability of Sam Splint. These local creases could in fact remain undetected when covered by cloth. Thus, the reusability of Sam Splint is confirmed.

Apart from the tests, there were three major observations, two relating to its thickness. First, the Sam Splint was comparable in thickness to the current velcro straps. This eliminates the concern of an overly heavy restraint on the infant. However, the Sam Splint was unable to remain propped up and instead fell under its own weight when pulled from certain angles. For example, propping up the straps by pushing up at the intersection succeeded, but pushing up from the back tails of the strap did not. Further testing should be performed to find a ratio of foam to aluminum that creates an ideal center of mass/rigidity such that all positions are tolerated. This preserves and reinforces the intended function: that the unused strap would remain propped up and ready to use for the next transport - thus limiting the need to reach over the infant. Finally, sometimes the center of the ‘X-shaped’ strap becomes misaligned from the baby’s midline. This can be fixed by adding additional attachment points near the center of the strap, and having two, instead of one, straps.

V. Conclusion

As a result of this performance testing, the advantage of snap buttons over velcro and the viability of the Sam Splint have become validated. The ‘X-Shaped’ Strap in two components is also deemed to be as effective, if not more, than the current restraints. Still, there are important modifications to be made to the design. First, developing a Sam-Splint-like material with a thicker aluminum layer can help the straps remain freestanding in multiple positions. Then, we will finalize an alternative to superglue for attaching the snaps buttons onto our straps. We predict that the addition of an outer nylon cloth will allow us to insert these buttons directly into the strap. Finally, we plan to include a small loop, made of the same nylon as the cloth, to the end of each strap to make it easier to detach buttons.

VI. Citations

[20] J. Erich, "Acceleration Forces," *EMS World*, 30-Sep-2010. [Online]. Available: https://www.emsworld.com/index.php/article/10319229/acceleration-forces. [Accessed: 24-Feb-2021].