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The Design and Development of a Device to Assist in Boosting Patients

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Abstract

A common task a nurse is required to perform is called boosting patients. Boosting a patient is defined as lifting or sliding a patient back up in the bed after having slid down (Mannheim, Zieve, & Conaway, 2017). The current method for boosting patients involves a minimum of two personnel and an 11-step process. The 11-step process requires the person to manually lift and pull the patient using an existing half sheet on the bed (Mannheim, Zieve, & Conaway, 2017). Patients who cannot move or support themselves are moved every two to six hours or upon request (Bihn, Rieckhoff, Burkman, & Neumann, 2018). An ideal boosting device would only require one operator, have three operating steps, use minimal manual force, and pull a patient weighing up to 500 lbs. A prototype was developed incorporating the following features: pulling strap, clamps, and brackets. The prototype was able to pull 400 lbs. during testing, only requires one operator and eliminates manual labor. The main concern of the prototype is the longevity of the device because it requires the repeated use of the hospital bed mechanics. The next steps for the device are to update materials to be lightweight or washable and design a containment unit for the straps. It is recommended to incorporate the device into new designs of hospital beds for future use.

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CHAPTER 1 INTRODUCTION

1.1. PROBLEM STATEMENT

A common task a nurse is required to perform is called boosting patients. Boosting a patient is defined as lifting or sliding a patient back up in the bed after the patient has slid down toward the foot of the bed (Mannheim, Zieve, & Conaway, 2017). The current method for boosting patients recommends two direct care employees to perform the task. The suggested procedure is:

1. Tell the patient what you are doing
2. If you can, raise the bed to a level that reduces the strain on your back.
3. Make the bed flat.
4. Roll the patient to one side, then place a half rolled-up slide sheet or draw sheet against the person's back.
5. Roll the patient onto the sheet and spread the sheet out flat under the person.
6. Make sure the head, shoulders, and hips are on the sheet.
7. Grab the slide sheet or draw sheet at the patients' upper back and hips on the side of the bed closest to you.
8. Put one foot forward as you prepare to move the patient. Put your weight on your back leg.
9. On the count of three, move the patient by shifting your weight to your front leg and pulling the sheet toward the head of the bed.
    a. If the patient can help you, ask the patient to:

i. Bring the chin up to the chest and bend the knees. The patient's heels should remain on the bed.

ii. Have the patient push with the heels while you pull up.

10. You may need to do this more than once to get the person in the right position.

11. If using a slide sheet, make sure to remove it when you are done. (Mannheim, Zieve, & Conaway, 2017)

Due to the high demand for performing this task, nurses often strain their backs or shoulders (Bihn, et al., 2018). The number of injuries exists as an ongoing problem and will get worse in the future due to increasing obesity rates and the aging of the nursing workforce. Current solutions to this growing problem are inadequate because they are time-consuming, complicated to operate, and require multiple people.

1.2. TECHNICAL APPROACH

The project entailed a complete engineering design process. A prototype was designed, analyzed, built, and tested. Primary research was conducted by observing and interviewing direct care employees on the job. The direct care employees included Grand Valley State University nursing faculty, newly graduated nursing students and full-time, registered nurses. The observations and interviews were documented, analyzed, and compared to the published recommended procedures. Secondary research was used to investigate standard or recommended methods for boosting patients, and current products on the market for this task. The objective was to fill a void in the market that is cost-effective and less strenuous for nurses than the current methods. It was hypothesized that a cost-effective solution does not exist. Engineering specifications were created. The House of Quality was used to translate the needs into

specifications with optimal and marginal target values. A Function Structure Diagram was used to break down the overall function of the device into sub-functions. A variety of methods were used to generate solutions for each sub-function. Potential solutions to the sub-functions were documented using a morphological matrix. The generated ideas were used for concept development of an automated device. The Pugh Concept Selection Method was used to refine concepts and select concepts for further development. Top concepts were submitted to medical professionals for feedback via email. Upon selecting a final concept, verification activities were performed for top concepts to ensure feasibility. The verification activities included were stress analysis calculations, material analysis, and force calculations. Additionally, focused prototypes were manufactured and tested to reduce risk and evaluate concepts. After verification, a basic works-like prototype was built to show the overall function of the final prototype. Then, a final prototype was built after successful testing of the works-like prototype. The final prototype was tested by mimicking the conditions and environment it will be used in for functional validation. Lastly, cost and patent analyses were conducted to assess the marketability and manufacturability of the solution.

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CHAPTER 2 RESEARCH AND OBSERVATIONS

2.1. LITERATURE REVIEW

A survey of 357 critical care nurses showed that 45 percent boost patients 30 or more times per shift, 52 percent boost patients 10 – 20 times per shift, and four percent boost patients 20 – 30 times per shift (Sage Products, 2012). Due to the high demand for performing this task, nurses often strain their backs or shoulders. In the survey of 357 critical care nurses, it was confirmed that 93 percent of nurses reported injuries to themselves or a colleague from turning or boosting patients (Sage Products, 2012). Also, the Occupational Safety and Health Administration (OSHA) reports that 8 out of 10 nurses deal with musculoskeletal pain while on duty and that 24 percent change or leave shifts to recover from an unreported injury (Occupational Safety and Health Administration). For hospital workers, "48 percent of injuries resulting in days away from work are caused by overexertion or bodily reaction, which includes motions such as lifting, bending, or reaching." (Occupational Safety and Health Administration)

Table 2.1 shows the age of full-time equivalent (FTE), registered nurses from 2001 to 2015 (Buerhaus, Auerbach, Skinner, & Staiger, 2017). From 2001 to 2015, the percentage of FTE registered nurses above the age of 50 increased by 9.4 percent. The required tasks of nurses may become more dangerous and stressful for nurses of older age. The increasing age of nursing staff, combined with the increasing obesity rates, has contributed to the problem of injuries to nurses. For adults in the United States, obesity rates have increased by 9.1 percent for men and women from 1999 to 2016 (Hales, 2015-2016). As these trends continue, the problem of injuries to direct care employees gets worse.

Table 2.1. The ages of FTE registered nurses in 2001, 2005, 2010 and 2015 (Buerhaus, Auerbach, Skinner, & Staiger, 2017).

Age (years)	**2001**		**2005**		**2010**		**2015**	
	Total	Percent (%)	Total	Percent (%)	Total	Percent (%)	Total	Percent (%)
<35	497,150	23.8	491,505	21.0	627,790	23.1	875,795	27.5
35-49	1,020,394	48.9	969,645	41.4	991,823	36.4	1,145,887	35.9
50+	568,392	27.2	765,298	32.7	991,984	36.4	1,165,990	36.6
Total	2,085,937	-	2,339,315	-	2,721,934	-	3,187,672	-

For injuries on the job and reported, hospitals lose, on average, $0.78 per every $100 in payroll in workers' compensation costs (Occupational Safety and Health Administration). The average totals to $2 billion for the United States, annually (Occupational Safety and Health Administration). As the problem of injuries to direct care employees worsens, the cost hospitals must pay increases, which is why a solution is necessary. The proposed design will reduce injuries to medical professionals.

2.2. INTERVIEWS

Seven people were individually interviewed. Three interviewees were Grand Valley State University (GVSU) nursing faculty, and four interviewees were full-time, registered nurses. The questions and responses of each set of interviews can be found in Appendix A. The names of the interviewees are not used but denoted using letters. Below is a summary of relevant answers from each participant when asked how often a patient is boosted, who does the boosting, what type of patients need to be boosted most often, and how boosting is performed.

The first interviewee was a female with a Ph.D. in Nursing that has worked for 12 years at the College of Nursing at GVSU. She is a registered nurse, and her areas of interest and teaching include hospice and palliative care, living with life-limiting illnesses, and public health (Grand Valley State University, 2019). She stated, based on her experience, that nursing assistants boost patients 90 percent of the time, and immobile patients need boosting the most often. Also, the suggested method of boosting requires a minimum of two people pulling with the draw sheet, and patients are boosted every two to four hours.

The second interviewee was a female with a Master of Science in Nursing, over 20 years of nursing experience and has worked for the College of Nursing since 2007. She also teaches clinical and professional nursing (Grand Valley State University, 2019). She stated that nurses and nurse technicians do the most boosting every four to six hours, and a minimum of two people is required to boost. Also, the suggested method of boosting is to pull on the draw sheet from both sides of the bed, and patients in the medical surgical unit need the most boosting.

The third interviewee was a female registered nurse with board certification, a Doctor of Nursing Practice, and Master of Science in Nursing. She has been GVSU faculty since 2015 and specializes in promoting patient safety (Grand Valley State University, 2019). She said that nurses and technicians boost the most often whenever the patient needs to be boosted, obese people and patients right out of surgery need to be boosted the most often, and a minimum of two people is required.

The fourth interviewee was a female nurse educator at a local hospital. She has a Doctor of Nursing Practice and over seven years of experience as a registered nurse (LinkedIn, 2019). She said that nurses and nurse technicians do the boosting the most often, boosting a patient

occurs every two to four hours or upon request, and a minimum of two people is required to boost a patient by pulling the draw sheet on both sides of the bed.

The fifth, sixth and seventh interviewees were all females who recently graduated college and are registered nurses. The have about three years of experience each, in a variety of areas, such as hospice, adult medical surgery, and the newborn intensive care unit. These interviewees stated that patients are boosted every two to six hours, one to four people are required to boost, using the draw sheet is the most common method of boosting, and they have seen or heard of other employees getting injured frequently.

Finally, the eighth interviewee is a nurse practitioner who is also female. She has about seven years of experience and has an acute care pediatric nurse practitioner board certification. She stated that older nurses get hurt most often; the draw sheet is used most commonly to boost patients, and patients are boosted every two to four hours.

The information collected during the interviews is consistent with the literature search for the frequency of boosting and the recommended boosting process. Also, the interviewees stated that elderly nurses tend to struggle more with patient handling, as was found in the literature search. The nursing professionals interviewed were able to describe what patients most commonly need boosting, while the literature search provided costs to hospitals due to injuries. Additionally, the interviewees claimed that injuries are common; however, the number of injuries found from the literature search appear more prominent.

2.3. OBSERVATIONS

A two-hour observation/shadowing experience was conducted at a local Grand Rapids hospital. It was conducted on November 19, 2018. A tour was received of the facility and the participating department floors. Throughout the tour, conversations with about 15 nursing staff

occurred in passing or in between the nurses' responsibilities. The conversations ranged from 2 minutes to 15 minutes, depending on the availability of the employee. Additionally, patient boosting was observed.

When observing a patient with mobility getting boosted, it was noted that two people were required, the head of the bed was lowered flat; then, the two people grabbed either side of the draw sheet. The draw sheet was already on the bed and under the patient. The nurses pulled laterally along the bed. After the boost, there was about two minutes of adjusting the bed and pillows to a comfortable position for the patient. Estimated height and weight of the patient were 5 feet 6 inches and 200 lbs. Had the weight of the patient been more substantial, more people would have been required to boost the patient based on the 35 lb. lifting limit for nurses. Following the boost, there was a discussion of what tools are available for boosting heavier patients and where the tools are stored. Some available tools are ceiling lifts and friction-reducing sheets. Although there are transfer and positioning devices available, the preferred method stated by the nurses was to manually perform transfers and positioning due to the inconveniences of the other devices. The inconveniences described were where the devices are located, the complexity of operation, and the time required to operate the devices.

One large storage closet was observed with the patient moving/transferring devices. In this hospital, there are markers on the wall in the hallways every 25 feet for patient evaluation. Using the markers, it was estimated that nurses in the four neighboring departments on the third floor have to walk between 150 to 550 feet. This is equivalent to 0.59 minutes to 2.17 minutes if using the average 2.88 miles per hour (mph) walking speed of people 40 – 49 years of age (Schimpl, et al., 2011). Using an average salary of a registered nurse in Michigan of $69,000, it costs between $0.70 and $2.52 every time a nurse walks to and from the storage closet

(Glassdoor Inc., 2019). Given that nurses and nursing assistants have a lengthy list of responsibilities, this was a significant deterrent for using the equipment. Also, this would later influence the design of the device to be able to be stored on the bed or in the hospital room.

A ceiling lift was observed in an empty hospital room. This lift is typically used for transfers out of bed, rather than moving patients within the bed. However, this lift was either broken or had dead batteries when a demonstration was attempted. The nurse being shadowed also stated that new hires are trained on only some of the equipment during orientation the first day. The equipment is then rarely used, and most people do not remember how to use the equipment after orientation. Finally, the nursing manager of the third floor stated 50 percent of the rooms on the third floor are equipped with a ceiling lift. This percentage, however, varies from hospital to hospital and within each hospital system. Thus, the prototype must be simple to use so staff remember how to operate the device.

Lastly, it was recorded that for patients less than 240 lbs. in weight, two nursing staff are required for boosting. If a patient exceeds 240 lbs. in weight, then additional staff (to the two mentioned previously) must assist. According to the nursing manager of the third floor, a nurse must not lift more than 35 lbs. in any of the responsibilities a nurse has. A lifting limit of 35 lbs. is a standard set by the National Institute for Occupational Safety and Health (NIOSH) for all lifting tasks (Waters, Putz-Anderson, & Garg, 1994).

Consequently, the maximum lifting limit would later influence the design to minimize the manual force of the user when operating the prototype.

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CHAPTER 3 SPECIFICATIONS

3.1. INTERPRETED NEEDS AND ENGINEERING CHARACTERISTICS

The interpreted needs were translated into engineering characteristics based on the primary and secondary research. The needs and characteristics can be found in Table 3.1 below, and the full house of quality is in Appendix B.

Table 3.1. The interpreted needs and engineering characteristics of the problem.

#	**Interpreted Need**	**Engineering Characteristic**	**Units**
1	The setup needs to be simple.	Steps prior to boost	Number of steps
2	The boosting process can be executed quickly.	Boost time	Seconds
3	Quick to disassemble.	Take-down time	Seconds
4	Minimal people required for operation.	Number of operators	Number of people
5	Compatible with beds.	Percent of compatible beds	Percentage
6	The device moves large patients.	Weight of the patient	lbs.
7	The device moves the patient safely.	Success rate of patient being moved safely	Percentage
8	The device operates normally after repeated use.	Lifecycle	Number of uses
9	The device reduces manual labor for user.	Amount of weight pulled by the user	lbs.
10	The device is cost effective.	Manufacturing cost	Dollars
11	The device completes the transfer fully.	Max distance pulled	in./ft.
12	The device is quiet.	Sound pressure level	dB

The justifications of the specifications for the device are in Table 3.2.

Table 3.2. The justifications for the target values and specifications.

#	Engineering Characteristic	Units	Ideal and Marginal Targets	Justification for Ideal and Marginal target values?
1	Steps to operate	Number of steps	Ideal: 3 Marginal: 5	The current manual process requires 7 steps.
2	Patient moving time	Seconds	Marginal: 3<x<6 s Ideal: 2.5<x<5 s	During the manual boosting process, the patient is physically being moved for roughly 2-3 seconds. The manual process is abrupt, thus, to create safer conditions for the patient the moving time can be slower with the device.
3	Take-down time	Seconds	Marginal: 30 s Ideal: 20 s	The time to take down the device should be minimal given. If the device takes too long to take-down, the appeal of the device decreases.
4	Number of operators	Number of people	Ideal: 1 Marginal: 1	The current, manual boosting process that is the most common takes a minimum of 2 people. If the weight of the patient exceeds 240 lbs., then at least 3 people are required to move the patient. The people required to use this device should be one in order to increase the economic feasibility of the device.
5	Percent of compatible beds	Percentage	Ideal: 90% Marginal: 80%	In one hospital building the style of bed can change from each department. From hospital to hospital, the brand and style can change. Marginally, the device should operate successfully on 80% of the hospital beds on the market which are Hill-Rom or Stryker. Ideally, the device would work for almost any bed whether it is Hill-Rom/Stryker or not.

6	Weight of the patient	lbs.	Marginal: 350 lbs. Ideal: 500 lbs.	The weight of American adults is on the rise. Patients have a large range of weight, so the device should be able to operate for the maximum weight outside of the bariatric unit. Bariatric patients weigh 350 lbs. or greater (Muir & Archer-Heese, 2009). Ideally, the device could work for more than 350 lbs. and work for the 500 lb. capacity of the hospital bed.
7	Success rate of patient being moved safely	Percentage	Ideal: 100% Marginal: 100%	The patient should be successfully, safely, and comfortably moved every time the operation occurs.
8	Lifecycle	Number of uses	Marginal: 21,900 Ideal: 43,800	Assuming patients are boosted 20 times a shift by one nurse, the device would be used for 4,380 boosts in one year. The device should last for at least 5 years and ideally it would last 10 years. The device should have to have minimal maintenance in a 5-year span, and not be replaced until at least 5 years of use.
9	Amount of weight pulled by the user	lbs.	Marginal: 35 lbs. Ideal: 0 lbs.	A nurse is required to be able to lift up to 35 lbs. A nurse is not allowed to lift more than 35 lbs., otherwise another person or a device is required to complete the task at hand. The device should minimize the amount of weight the user must pull/lift. Ideally, the device should be fully automated so the operator does not have to lift or pull any weight.
10	Manufacturing cost	Dollars	Marginal: $7,000 Ideal: $5,000	The total potential value per device was calculated to be $167900. The manufacturing cost is projected to be 25% of the total value. Ideally, the manufacturing cost would be low without reducing quality.

				The value analysis is described below.
11	Max distance pulled	in.	Ideal: 13 in. Marginal: 8 in.	The current, manual boosting process moves a patient anywhere from 6 to 12 inches depending on the patient and how far down the bed he/she has moved.
12	Sound pressure level	dB	Marginal: 45 dB Ideal: 0 dB	45 dB is the sound level that is louder than a whisper but quieter than a normal conversation (Dima, 2017).

Value analysis is used to estimate how much the device is worth to the potential buyer. The first step for the value analysis is to determine what a registered nurse in the United States earns per minute. The amount is calculated using equation 3.1 using an average base salary of $69,000 (Glassdoor Inc., 2019).

$$\left(\frac{\$69000}{Year}\right)\left(\frac{1\,Year}{50\,Weeks}\right)\left(\frac{1\,Week}{40\,Hours}\right)\left(\frac{1\,Hour}{60\,Minutes}\right) = \frac{\$0.575}{Minute} \tag{3.1}$$

This calculation assumes that the nurse works 50 weeks out of the year and works 40 hours per week. Next, the current cost per boost is calculated. Equation 3.2 calculates the cost for two nurses two boost a patient with the current method.

$$\left(\frac{7\,Minutes}{1\,Boost}\right)\left(\frac{2\times\$0.575}{Minute}\right) = \frac{\$8.05}{Boost} \tag{3.2}$$

The worker's compensation cost is calculated in equation 3.3. As stated in section 2.1, hospitals lose, on average, $0.78 per $100 in payroll for worker's compensation.

$$(\$8.05)\left(\frac{\$0.78}{\$100}\right) = \$0.06 \tag{3.3}$$

The cost per boost currently (Equation 3.4) is the sum of the costs calculated in equations 3.2 and 3.3.

$$\$8.05 + \$0.06 = \$8.11 \tag{3.4}$$

The cost per boost with the envisioned system is determined next. The cost of one nurse's time is calculated because the proposed device will only require one user.

$$\left(\frac{3\ Minutes}{1\ Boost}\right)\left(\frac{\$0.575}{Minute}\right) = \frac{\$1.73}{Boost} \tag{3.5}$$

The proposed device is assumed to reduce the worker's compensation costs by 10 percent.

$$(\$1.73)\left(\frac{\$0.78}{\$100}\right)(0.90) = \$0.01 \tag{3.6}$$

The total cost per boost with the envisioned system is the sum of equations 3.5 and 3.6.

$$\$1.73 + \$0.01 = \$1.74 \tag{3.7}$$

The value per boost is the difference between the current cost and the proposed cost to boost.

$$\$8.11 - \$1.74 = \$6.37 \tag{3.8}$$

Determination of the total value of the device based on its suggested lifespan is below using equation 3.9. A ten-year lifespan is assumed based on the ideal target value in Table 3.2. It is also assumed a nurse will boost one patient five times per shift, given that a nurse may complete a total of 20 boosts per shift and cover four beds per shift (Bihn, et al., 2018)

$$\left(\frac{\$6.37}{Boost}\right)\left(\frac{10\ Years}{1\ Lifetime}\right)\left(\frac{5\ Boosts}{1\ Day}\right)\left(\frac{365\ Days}{1\ Year}\right) = \$116{,}000\ per\ bed\ per\ lifetime \tag{3.9}$$

Additionally, the selling price and the manufacturing revenue are estimated by calculating a reduction of the total value of the device. One-third of the total value of the device was assumed to equate to the selling price. The potential manufacturing revenue was assumed to be one-fourth of the selling price. The calculation of the selling price and the manufacturing

revenue are found in equations 3.10 and 3.11. The value of the device is high relative to the potential manufacturing cost.

$$(\$116000)(0.33) = \$38000 \tag{3.10}$$

$$(\$38000)(0.25) = \$9{,}500 \tag{3.11}$$

Finally, the options of producing a retrofittable device or a device to be incorporated into new hospital beds are compared. Hospital beds, on average, cost between $5,000 and $40,000 depending on the type of bed (Rubenfire, 2015). If the cost to manufacture the device is higher than the cost of a hospital bed, then the device should be incorporated into new hospital beds. If the cost to manufacture the device is less than the cost of a hospital bed, then it could be an add-on to beds or incorporated into new beds.

3.2. FUNCTION STRUCTURE DIAGRAM

A function structure diagram (FSD) was created to break down the overall function of the device into simpler functions. In Figure 3.1, the function structure diagram is shown.

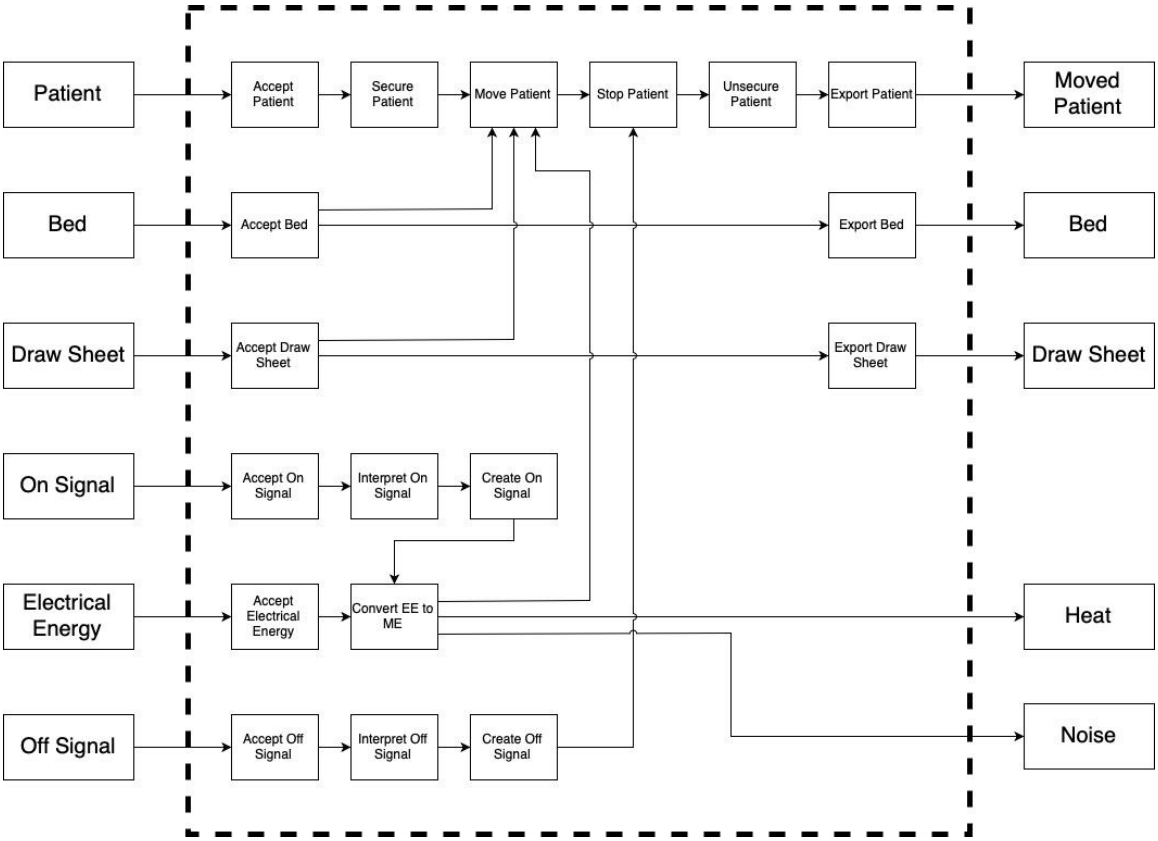

Figure 3.1. The FSD for the device.

The overall function of the device is to boost the patient. Boosting the patient requires the use of the inputs to move the patient.

The inputs of the device are the patient, bed, draw sheet, start and finish signal, and electrical energy. The inputs are what go into the device and are present at the start of the operation. The patient, bed, and draw sheet are all physical inputs that exist. The patient and draw sheet are being acted on, and the bed is the location of the operation. The electrical energy

and the start and finish signals are inputs that control the device. The electrical energy is used to power the device, while the on and off signals dictate when operating begins and ends.

The outputs of the device are the moved patient, bed, draw sheet, heat, and noise. The outputs are what comes out of the device and are present at the end of the operation. The moved patient, bed, and draw sheet are all physical outputs that exist. The moved patient is the result of the function of the device, and the bed is the location of the completed operation. Heat and noise are outputs that are generated from the conversion of electrical to mechanical energy.

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CHAPTER 4 CONCEPTUAL TESTING

4.1. CONCEPT GENERATION

Existing products for boosting patients were researched. Two types products found were friction-reducing materials and movable frames. An example of a friction-reducing product is a sliding sheet or pad with handles around the edges (Grainger Inc., n.d.). Figure 4.2 shows the sliding sheet. Numerous other products exist that vary slightly from the sliding sheet shown in Figure 4.1. The advantage of using a sliding sheet is it creates a slicker surface for sliding patients, which in turn reduces the manual force of the user.

Figure 4.1. The sliding sheet (Grainger Inc., n.d.).

The movable frame products are metal structures that hang over the hospital bed and, typically, would be stored in a storage closet and accessed when needed. One movable frame product is called the ErgoNurse. The ErgoNurse is a stand on wheels that suspends over the bed (ErgoNurse Inc.). Figure 4.2 shows the ErgoNurse. The rails above the bed and patient have retractable straps that can be used for repositioning and boosting patients. The advantage of the ErgoNurse is that it is multifunctional, meaning it can be used for turning patients, boosting

patients, or other patient handling needs. The ErgoNurse also limits the manual force required during patient handling.

Figure 4.2. The ErgoNurse (ErgoNurse Inc.).

Also, a product that can be used for boosting patients is the Hoyer Lift or devices similar to a lift (1800WheelChair, n.d.). Figure 4.3 shows a Hoyer Lift. The Hoyer Lift, in this case, is a movable frame product. A similar product is a ceiling lift, which also involves a sling, functions the same as a Hoyer Lift, but is mounted in the ceiling. A Hoyer Lift is typically used for patient handling in and out of a hospital bed, whereas the proposed prototype is used for patient handling within the hospital bed. The Hoyer Lift is a device that is stored in a hallway closet and uses a sling to move patients (1800WheelChair, n.d.). Reducing the strain on the user is an advantage of the Hoyer Lift. A Hoyer Lift allows for one direct care employee to assist larger patients without the help of additional staff.

Figure 4.3. The Hoyer Lift (1800WheelChair, n.d.).

The three products mentioned do not meet the needs of the user. The ErgoNurse and the Hoyer Lift have large footprints which take away space in an already cluttered hospital room. The time to operate the ErgoNurse and the Hoyer Lift would not meet the specifications, and the devices would require too many steps to operate. The sliding sheet requires manual force by the user which is desired to be eliminated. Additionally, the sliding sheet and the Hoyer Lift require the patient to be rolled to one side, which takes time and requires poor ergonomics by the user. Because the devices fail to meet all of the needs of the user, new ideas were devised.

Four brainstorming sessions were held to generate concept ideas for the device. The five sessions were comprised of one individual ideation session and four group ideation sessions. The procedure for brainstorming is found in Appendix C. The four group sessions were comprised of three different groups of people: non-engineering, engineering professors, and current engineering students. Two group sessions were conducted using current engineering students. The individual ideation session was used to generate ideas for the critical sub-functions (secure patient, move patient, and apply force), while the group ideation sessions had a mixture of the sub-functions and overall function of the device. The three methods used for the group brainstorming methods were the Crawford Slip Method, the Mitsubishi Method, and the NHK Method (Dettmer, 2003; Tatsuno, 1990).

The ideas generated were analyzed and organized into a morphological matrix, which is found in Table 4.1. The morphological matrix was then used to generate five complete concepts of the device. The individual brainstorming session resulted in the highest quality ideas, but the professor session resulted in practical and realistic ideas. The two engineering student sessions provided a lower quality of results, most likely since the students were not invested in the concept. The non-engineering session provided the widest variety of results that lead to useful ideas.

Table 4.1. The morphological matrix.

	Secure Patient	**Move Patient**	**Apply Force**
Solution 1	Strap	Pull	Manual
Solution 2	Velcro	Launch	Winch
Solution 3	Rope	Push	Crank
Solution 4	Glue	Kick	Linear Actuator
Solution 5	Lock	Roll	Pulley
Solution 6	Clamp	Throw	Spring
Solution 7	Wrap	Dolly	Cranes
Solution 8	Pocket	Swing	Trolleys
Solution 9	Buckle	Slide	Lifting clamps
Solution 10	Zipper	Lift	vacuum cups
Solution 11	Seat belt	Drag	robot arm

Solution 12	Sling	Conveyor belt	Bed force (move bed up and down to pull patient up)
Solution 13	Suction	Draw sheet	Bladder under mattress to mimic a caterpillar movement
Solution 14	Pinch at waist	Patran sheet	Foot pedal
Solution 15	Thigh rest	Hoyer lift	Stairmaster
Solution 16	Replace bed sheet material	Ceiling lift	Hydraulic jack
Solution 17	Screw down the patient	Manual lifting	
Solution 18	Vest	Slingshot	
Solution 19	Speed bump in mattress	Slide board/mat	
Solution 20	Harness	Safety secure mobility sheet	
Solution 21	Cutout in bed	Linear bearings	
Solution 22	Vacuum holes	Carriages and guide rails	
Solution 23		Telescoping slides	
Solution 24		Mattress/draw sheet handles	
Solution 25		Roller system	
Solution 26		Teeter totter	
Solution 27		Tilt bed upside down/backward	
Solution 28		Lever	
Solution 29		Float (air hockey table)	
Solution 30		Bed with wheels	

The first concept was designed to boost the patient by pulling from the top of the bed. The concept utilizes the existing draw sheet on the hospital bed, as well as the mechanics of the hospital bed. A strap is anchored on the bed frame and attaches to the draw sheet around the bed via clamps. To pull the patient, the user vertically raises the hospital bed with the existing push button, located on both sides of the bed and sometimes at the foot of the bed. As the bed raises, the straps will tighten, thus pulling the patient and draw sheet upward in the bed. The user stops pushing the button when the patient is in a good position. Figure 4.4 displays the sketch of the first concept.

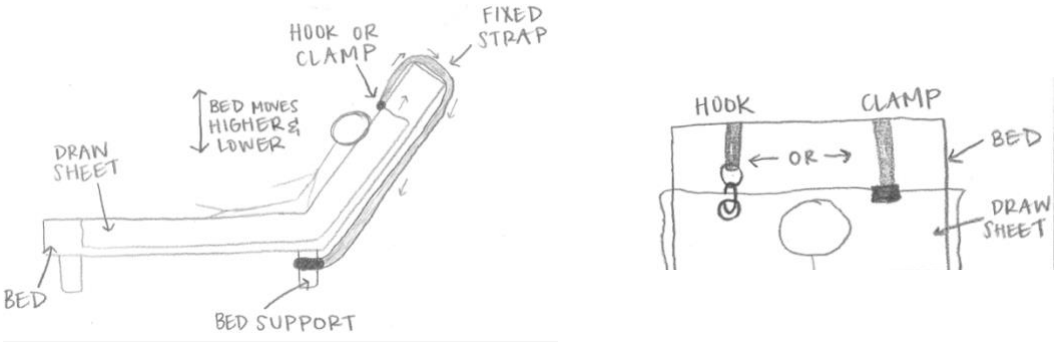

Figure 4.4. The sketch of the first concept.

Other variations of this concept include raising or lowering the head of the bed to pull the patient and using a rotatable bar at the head of the bed to reel in the straps powered by an external motor, winch, or hand crank system. Considerations for this concept entailed using a padded strap to protect the bed and using a low-friction strap material.

The second concept assists from the side of the bed by using a slide rail system and a clamp. The rail and clamp system would attach on both sides of the hospital bed. The existing draw sheet would get clamped in on the sides, and the user could then use a handle to slide the patient up the bed with the sliding system. The sketch of this concept is found in Figure 4.5.

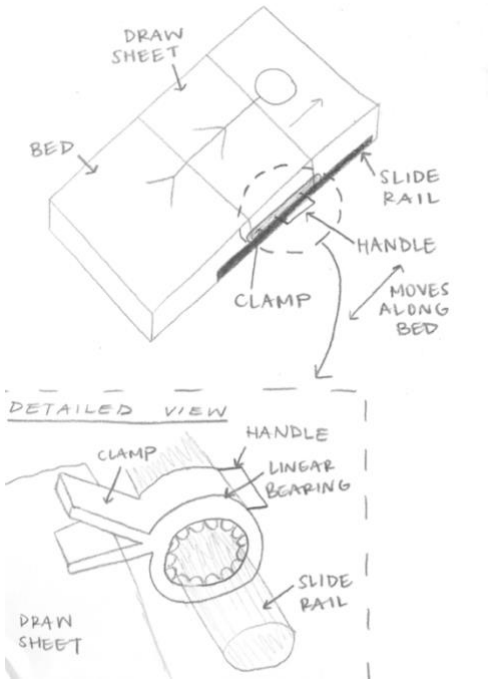

Figure 4.5. The sketch for the second concept.

Other variations of this concept include using a guide rail (similar to sliding drawers) or telescoping slides instead of linear bearings. Considerations of this concept entailed having a large clamping surface area to reduce the chances of ripping the draw sheet, handles and sliding system on both sides of the bed, and having the slide rails encompass almost the full length of the bed.

The third concept was designed to either prevent sliding or reduce friction. Concept 3a involved preventing the patient from sliding down the bed with rubbery pads. The rubbery pads would be in a cutout of the mattress and in the place wear a patient's back and lower extremities would be. The user would then either not have to perform the boosting task or have to perform the task significantly less. Concept 3b mimicked friction-reducing furniture-moving pads. The top of the pads would be a rubbery and or foam material to increase friction, while the bottom of the pad would be a frictionless plastic material. The user would place the pads underneath the

sides of the patient and use the current method of boosting patients. A sketch of concept three can be found in Figure 4.6.

Figure 4.6. The sketches for the third concept.

Considerations of concept 3a included a breathable rubber material, rubber on both sides of the pad if not in the mattress and creating more pressure sores or causing more irritation. Considerations of concept 3b included using a reeling system with multiple pads, using washable materials, and sizing the pads to accommodate most patients.

The fourth concept was also designed to prevent sliding. This concept uses a harness with Velcro on the back and Velcro on the bed. The patient wears the harness with the Velcro on the bed to prevent sliding. A sketch of the fourth concept can be found in Figure 4.7. Other variations of this concept include a harness with loops/handles for either pulling or attachment, a harness with a rubbery back, or a harness being attached to the top of the bed. Some considerations for this concept were using a comfortable and washable material and having a variety of sizes or adjustable sizing for the harness.

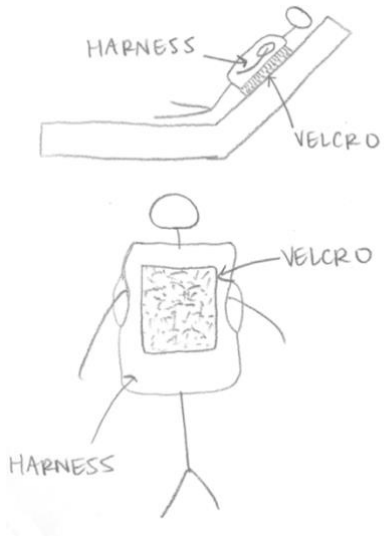

Figure 4.7. The sketch for the fourth concept.

The fifth concept involved a harness for the nurses and nursing assistants to wear. The idea developed from using proper ergonomics to lift and also to promote proper posture. A similar product exists as a harness used for moving heavy furniture. The user would wear this harness around the waist and legs. The hospital bed would be lowered vertically so that the patient was level with the users' knee area. A connecting strap would go underneath the patient to the other side/the other users' harness. The users would use a squatting motion to slightly lift the patient followed by a lunging side step to slide the patient up the bed. A sketch of this concept can be found in Figure 4.8. Some considerations for this concept included a washable and comfortable material, using clamps or hooks to attach on to the draw sheet and having adjustable sizing for the harnesses.

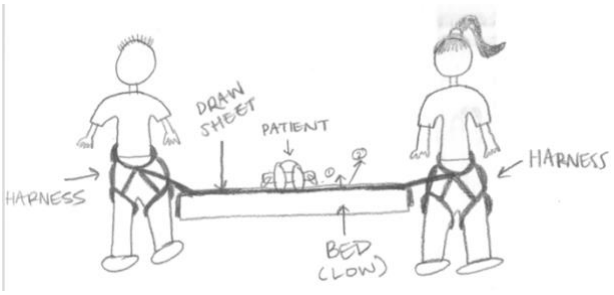

Figure 4.8. The sketch for the fifth concept.

4.2. PUGH CONCEPT SELECTION METHOD

Nursing professionals reviewed the five concepts. The reviewers were asked to provide advantages and disadvantages to each concept and rank the concepts from best to worst. Five of the nine reviewers asked responded with feedback. Table 4.2 shows the total number of votes each concept received. Concept one received the most votes as the "best" concept, followed by concept two. The first and second concepts were selected to move forward for further consideration. The remaining three concepts were eliminated due to lack of feasibility and the comments received from the reviewers.

Table 4.2. The total number of votes for the concepts reviewed.

Concept	**1 (Best)**	**2**	**3**	**4**	**5 (Worst)**
1	3	2	0	0	0
2	2	1	2	0	0
3	0	2	2	0	1
4	0	0	0	0	5
5	0	0	0	5	0

Concept one moving forward will be referred to as "Bed Mechanics", while concept two will be referred to as "Side Slide". Two other variations of the bed mechanics concept were also

taken into consideration. These two concepts are named “Hand Crank” and “Motorized”. Figures 4.9 and 4.10 show the sketches for the Hand Crank and Motorized concepts.

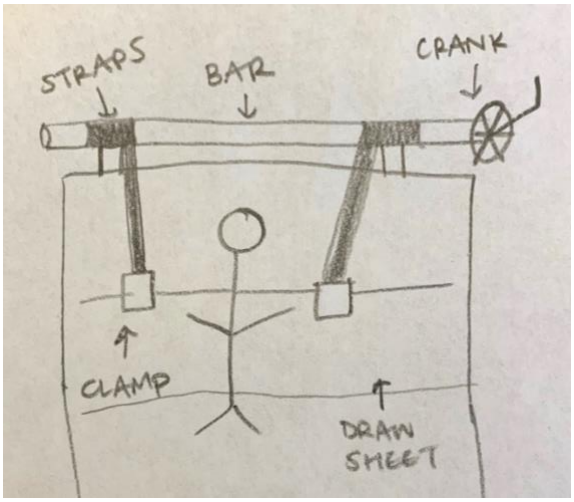

Figure 4.9. The sketch for the Hand Crank concept.

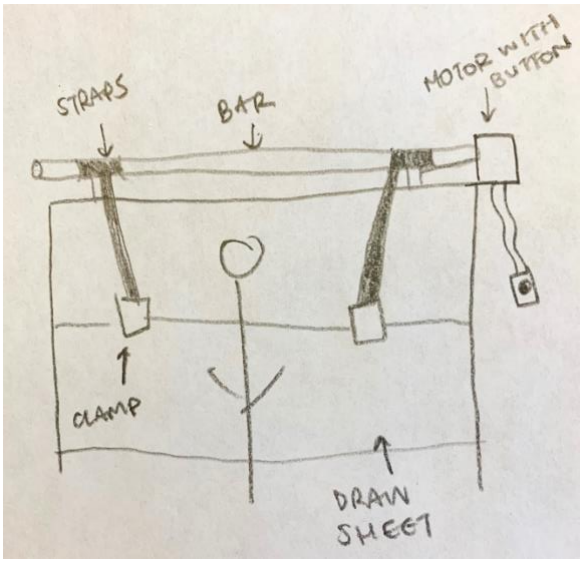

Figure 4.10. The sketch for the Motorized concept.

The Pugh Concept Selection Method was used to narrow the top four concepts down (Pugh, 1996). The goal was to select the final concept to pursue with prototyping. Table 4.3 describes the criteria used in the selection method. Tables 4.7 – 4.7 present the descriptions of each concept.

Table 4.3. The descriptions of the criteria used in the Pugh Concept Selection Method.

Criterion	Description
Number of Steps	The number of steps required to setup, use, and take down the device and or complete the boosting process
Manufacturing Cost	The cost of manufacturing. For this case, it would be based off of the availability and type of components in the device
Ease of manufacturing	How quickly and efficiently the device can be manufactured, the complexity of the device, and the manufacturing processes required to produce the device
User Force Required	How much the user is required to manually do during setup, operation or take down
Bed compatibility	The percentage of hospital beds the device could be used on/with
Footprint	How much space is taken up by the device in the hospital room

Table 4.4. The description of the Side Slide concept.

Operated	Attached to bed	Stored (not in use/empty bed)	Stored (not in use/patient in bed)
The device assists the user from the side of the bed. The device consists of the sliding assembly, clamp and handle. The sliding assembly is constructed of industrial linear rails, bearings and a handle. The clamp is attached to the bearings on the rail, which is where the draw sheet is clamped down in. The handle is where the user can grab onto to mimic the current method of boosting, only the sliding mechanism provides an assistive force due to the bearings. The device would best be operated with the bed at a horizontal level, similar to how the current method of boosting is performed. When the patient has been boosted to an appropriate position, the user can unclamp the draw sheet and either slide the bearings back down to the starting point.	This device would be attached to the bed with a metal plate, similar to what was used for a different project. Because the sides of hospital beds have limited space, the metal sheet will allow for an inconspicuous placement. The rails would be attached to the metal plate. Because the mattress and patient would be on top of the metal plate, the device should be secured.	When this device is not in use and there is no patient in the bed, the device would sit on the hospital bed out of the way because it is mainly under the mattress.	When this device is not in use but there is a patient in bed and could be used at any moment, the metal plate is still under the bed, the bearings are on the rails toward the foot of the bed and the clamp and handle are ready to be used.

Table 4.5. The description Bed Mechanics concept.

Operated	Attached to bed	Stored (not in use/empty bed)	Stored (not in use/patient in bed)
The device uses the existing bed mechanics to pull the patient from the top of the bed. The device consists of the strap, reel, housing unit, and attachment piece. The reel is the base of the strap that is stable underneath the bed. The housing unit is at the head of the bed and prevents the attachment piece from snapping on the user and under the bed. When the patient needs to be boosted, the user grabs the attachment piece to attach to the existing draw sheet. The attachment piece is connected on both sides of the patient above the head near the corners of the draw sheet. When attached, the user pushes the button to raise the whole bed vertically. As the bed raises, the straps will remain tight thus pulling the patient upward. The user then releases the button when the patient has been boosted into an appropriate position. The user can then detach the attachment piece and store it in the housing unit, or the user can leave the attachment piece on and ready for the next boost.	Hill-Rom and Stryker beds have a place underneath the bed for the base of the straps. If not, the head board is a possible attachment point for the base of the straps. The base of the straps would be a reel for the strap to wind up on and come out of during use. At the top of the bed, there would be a housing unit for the end of the straps where the attachment point to the sheet is. The housing unit would allow the user to easily grab the attachment piece to put on the draw sheet without the piece being under the bed or hard to reach. The housing unit would have the ability to be detached if needed.	When this device is not in use and there is no patient in the bed, the device would have the attachment piece in the housing unit and not connected to the draw sheet, or the device would have the straps reeled in underneath the bed and the housing unit sitting on top. If the device is not needed on the bed, it would need to be stored in a closet in the room or in a hallway.	When the device is not in use but there is a patient in bed and could be used at any moment, the attachment piece would be in the housing unit at the top of the bed ready. The device could, also, potentially stay attached to the draw sheet even when not in use for boosting.

Table 4.6. The description of the Hand Crank concept.

Operated	Attached to bed	Stored (not in use/empty bed)	Stored (not in use/patient in bed)
The device uses a crank stand that stands between the head of the bed and the wall. The stand consists of a hand crank, reel, strap, attachment piece and housing unit. The crank and reel combined are what pull the strap and patient up. The attachment piece is the clamp like object that attaches to the draw sheet and exists at the end of the strap. The housing unit is at the head of the bed and prevents the attachment piece from snapping on the user and under the bed. When the patient needs to be boosted, the user grabs the attachment piece to attach to the existing draw sheet. The attachment piece is connected on both sides of the patient above the head near the corners of the draw sheet. When attached, the user then uses the hand crank to reel in the strap. Thus, the patient is pulled up the bed until in a suitable position. The user can then detach the attachment piece and store it in the housing unit, or the user can leave the attachment piece on and ready for the next boost. The device could be on wheels with a locking mechanism to ensure that during use the device would not roll, but when not in use it could be moved.	N/A	When the device is not in use and there is no patient in the bed, the device would have the attachment piece in the housing unit and not connected to the draw sheet. The stand would be between the bed and the wall. If the device is not needed in that particular room, it could be stored in a closet in the hallway.	When the device is not in use but there is a patient in bed and could be used at any moment, the attachment piece would be in the housing unit at the top of the bed ready. The device could, also, potentially stay attached to the draw sheet even when not in use for boosting.

Table 4.7. The description of the Motorized concept.

Operated	Attached to bed	Stored (not in use/empty bed)	Stored (not in use/patient in bed)
The device uses a motorized reel stand that stands between the head of the bed and the wall. The stand consists of an electric motor, reel, strap, attachment piece and housing unit. The motor and reel combined are what pull the strap and patient up. The attachment piece is the clamp like object that attaches to the draw sheet and exists at the end of the strap. The housing unit is at the head of the bed and prevents the attachment piece from snapping on the user and under the bed. When the patient needs to be boosted, the user grabs the attachment piece to attach to the existing draw sheet. The attachment piece is connected on both sides of the patient above the head near the corners of the draw sheet. When attached, the user then holds a button down to activate the motor and reel the strap in. Thus, the patient is pulled up the bed until in a suitable position. The user can then detach the attachment piece and store it in the housing unit, or the user can leave the attachment piece on and ready for the next boost. The device could be on wheels with a locking mechanism to ensure that during use the device would not roll, but when not in use it could be moved.	N/A	When the device is not in use and there is no patient in the bed, the device would have the attachment piece in the housing unit and not connected to the draw sheet. The stand would be between the bed and the wall. If the device is not needed in that particular room, it could be stored in a closet in the hallway.	When the device is not in use but there is a patient in bed and could be used at any moment, the attachment piece would be in the housing unit at the top of the bed ready. The device could, also, potentially stay attached to the draw sheet even when not in use for boosting.

The Bed Mechanics concept represents the “baseline concept” to compare the other concepts. Table 4.8 shows the first round of the Pugh Concept Selection Method. Concepts received a mark as better, worse, or the same as the baseline concept for each of the criteria. Better is marked as “+”, worse is marked as “-”, and same is marked as “S”. Table 4.8 shows that all concepts failed to meet the criteria as well as the baseline concept.

Table 4.8. The first round of the Pugh Concept Selection Method.

Criteria	Side Slide	Bed Mechanics	Hand Crank	Motorized
Minimal operating steps	-	Baseline Concept	S	S
Cost	-		-	-
Ease of manufacturing	-		-	-
Minimal manual force	-		-	S
Bed compatibility	S		S	S
Footprint	S		-	-

Each of the negative attributes were investigated for improvement. For the Side Slide, the cost of the components could be researched fully to find the best price. The device could consist of “off-the-shelf” components to make manufacturing easier. A high dynamic and static load rating would be required for the bearings to assist in sliding, and the number of steps to operate this device will always be higher than the baseline. For the Hand Crank, the cost of the components would be researched fully to find the best price, and the device could use “off-the-shelf” components, as well, to increase the ease of manufacturing. The gear ratio for the crank would be tested and adjusted to minimize the manual force required. If a durable attachment point was discovered at the head of the bed, the footprint could be reduced. The Motorized concept could be improved if the cost of the components was researched entirely, and “off-the-shelf” components were used to aid in manufacturing. If a durable attachment point was discovered, then the footprint could be reduced, also.

With the new revisions to each of the concepts, a second round of the Pugh Concept Selection Method was conducted (Table 4.9). Although the concepts improved, none of them compared to the Bed Mechanics device. The negatives remaining could not improve based on the overall requirements of the devices; thus, the selection was stopped after the second round. The Bed Mechanics method was selected as the top concept to move forward with prototyping.

Table 4.9. The second round of the Pugh Concept Selection Method.

Criteria	Side Slide	Bed Mechanics	Hand Crank	Motorized
Minimal operating steps	-	Baseline Concept	S	S
Cost	S		-	-
Ease of manufacturing	-		-	-
Minimal manual force	-		-	S
Bed compatibility	S		S	S
Footprint	S		S	S

4.3. WORKS-LIKE PROTOTYPE

An available hospital bed at Grand Valley State University's Center for Health Sciences (CHS) building was used to test the prototype. Straps and clamps were bought from a local hardware store. The bed used for testing was a Stryker 3005S3 model. With the purchased straps and clamps, testing was able to proceed. Figures 4.11 and 4.12 show the setup. The straps were wrapped around the frame of the bed and attached to the clamps.

Figure 4.11. The general setup of testing with the works-like prototype at CHS.

Figure 4.12. The attachment points of the straps.

During the second round of testing, the concept was successful for no weight on the draw sheet and with the human dummy that was initially on the bed. The human dummy weighs about 63 lbs. and was pulled approximately four inches. Issues that surfaced were the draw sheet slipping out from the clamps, the straps not adjusted to the proper length, and the bed not traveling enough for attempts with the volunteer. Other considerations during this testing were

how to avoid the headboard and improve the path of the strap. On another day of testing, the headboard was removed from the hospital bed. The setup can be viewed in Figures 4.13 and 4.14. During this day of testing, the device had better success pulling the dummy and also made improvements with the volunteer present. The dummy was pulled approximately seven inches, while the volunteer was pulled four inches. The main issue present during this day of testing was the lack of grip of the clamps purchased. To mitigate this, the volunteer on the bed held the clamps without resisting the pull of the straps. This action helped; however, it was not used in the continuation of testing, instead to justify updating the clamps.

Figure 4.13. The side view of the setup for the third round of testing.

Figure 4.14. The attachment points of the straps for the third round of testing.

4.4. REFERENCES

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CHAPTER 5 FINAL PROTOTYPE

5.1. COMPONENTS

The final prototype consists of two straps, clamps, and brackets. Figure 5.1 displays the entirety of the prototype. The brackets bolt onto the bed using existing holes in the frame of the bed. The brackets fit in front of the head board on both sides of the bed. The straps are looped through the clamp's eyelet and around the axel of the hospital bed. Figure 5.2 shows the general location of the strap attachment point. Figure 5.3 displays the sketch of the path of the straps. The clamps attach to the draw sheet that exists on every bed and is underneath the patient.

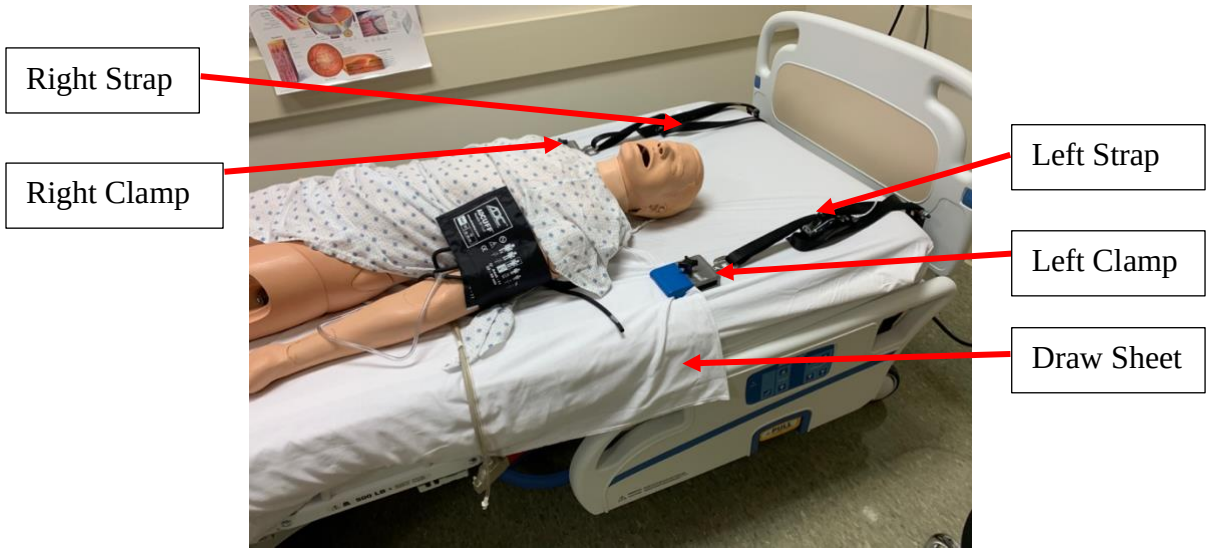


Figure 5.1. Overview of the prototype on the bed.

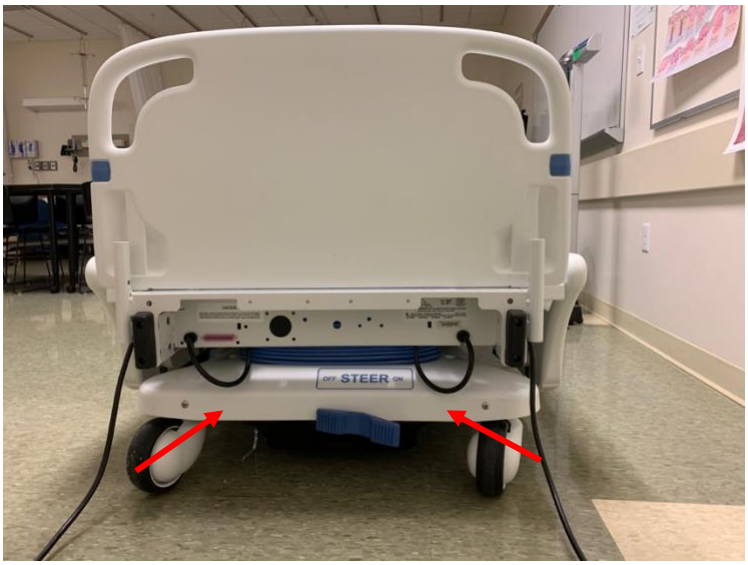


Figure 5.2. The attachment points for the straps. Underneath the plastic cover (red arrows), is a square metal frame that the strap is looped around.

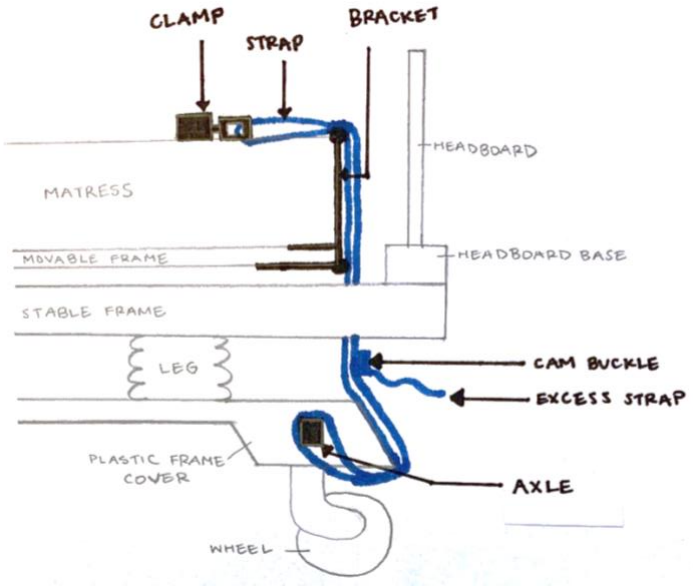


Figure 5.3. A sketch of the path of the straps.

Brackets

The design of the steel brackets prevent damage to the hospital bed and assist in the travel of the straps. Another design consideration was to ensure the brackets did not inhibit the range of motion of the bed. Figure 5.4 displays orthographic views of the bracket assembly. The bracket

consists of the base and two rollers. Brackets with 1-inch wide rollers and 2-inch wide rollers were created. One roller is on top of the bracket, while the second roller guides the strap down. The bracket fits on the edge of the frame and attaches with two bolts. The two versions were built to test which width kept the straps in place better due to the straps being one loop that overlaps itself. Both versions were tested, but the two-inch bracket was deemed the better option. Due to space restrictions, the depth of the brackets was limited to ¾ in.

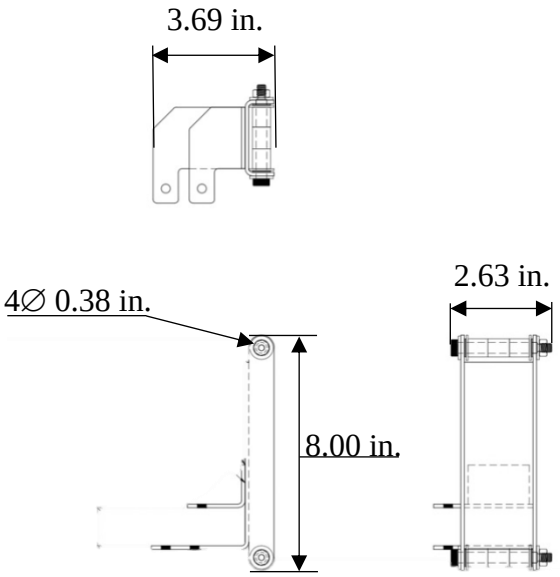


Figure 5.4. The orthographic views of the two-inch bracket.

The workable space between the bed frame and the headboard was one inch. Figure 5.5 shows an isometric view of the bracket off the bed, and Figure 5.6 shows the side view of one of the brackets on the bed. The brackets were designed with an "L-shape" base. The "L-Shape" avoids interfering with a weld and silicone pad underneath the frame of the bed. Figure 5.7 shows the weld and silicone pad. The brackets are 8 in. tall and weigh 1.4 lbs. each. The dimensional drawings are in Appendix D.

Figure 5.5. The two-inch bracket.

Figure 5.6. The side view of the two-inch bracket installed on the bed.

Figure 5.7. The weld and silicone tab underneath the frame.

Clamps

The steel clamps were designed to prevent tearing of the half sheet while also securing the half sheet to prevent slipping. The design of the clamps was inspired by pulling clamps, which are usually used for maintenance on conveyor belts, cars, or assembly lines. The head of the clamp was coated with rubber to increase the friction between the clamp and the sheet. The rubber coating is product 9560T7 from McMaster-Carr in blue. Figure 5.8 shows the clamp not in use, while Figure 5.9 shows the clamp in use.

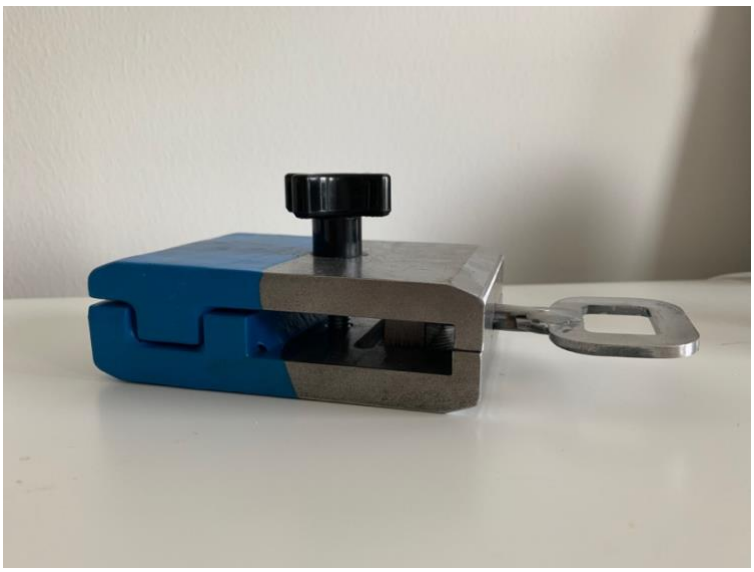


Figure 5.8. The clamp.

Figure 5.9. The clamp in use.

The handle screws through the clamp and secures the pieces together. The handle is used to adjust the jaws of the clamp. The straps are looped through the eyelet that protrudes out the back of the clamp. As the straps tighten, the eyelet is pulled, which provides a clamping force at the head of the clamp. An exploded view of the clamp can be found in Figure 5.10.

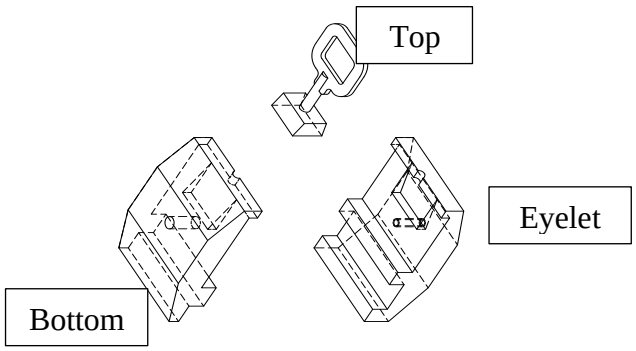


Figure 5.10. An exploded view of the clamp.

The free body diagrams of the clamp are found in Figure 5.11. The free body diagram represents the top half of the clamp. Equal and opposite forces act on the bottom half of the clamp. The pull force occurs at the end of the eyelet but is distributed throughout the whole eyelet. Half of the pull force is labeled as f_1 in the diagram where the eyelet makes contact with the top piece of the clamp. The center pin exists as the pivot point of the clamp, which is labeled as "o" on the free body diagram. The relationship between the pull force and the clamp force was derived using the following equation

$$\circlearrowleft \sum M_o = 0 = FD + f_3 d \tag{5.1}$$

where F = clamp force in lbs., D = distance from the clamp force to the pivot point in inches, f_3 = reaction force in lbs., and d = distance from the reaction force to the pivot point in inches. Equation 5.1 is simplified below (Equation 5.2).

$$F = -\frac{f_1 d \cos 12^\circ}{D \sin 12^\circ} = -3.16 f_1 \tag{5.2}$$

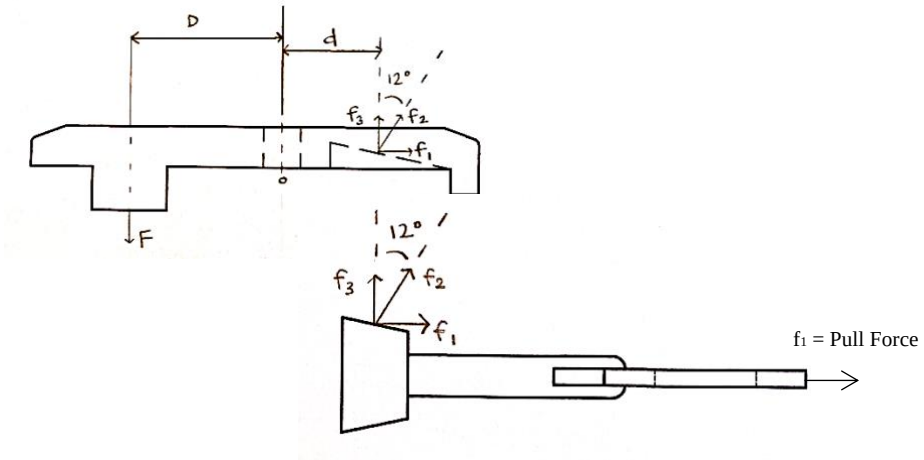


Figure 5.11. Free Body Diagrams of the clamp.

If a 500 lb. patient was pulled, then the resultant top clamp force would be 247.05 lbs. downward. The clamping force was calculated by substituting 78.185 lbs. for f_1 in equation 5.2, which is half of 156.37 lbs. from Verification Form #1. The total clamp force for pulling a 500 lb. patient is 494.1 lbs.

The clamps were designed to be three inches wide to provide a large enough surface area not to tear the sheet. The width was determined through trial and error of testing two other clamps. The first clamp used was about an inch wide with a smooth, rubber surface. This clamp did not tear the sheet; however, it did not secure the sheet. The second clamp used was about 1.5 inches wide with small, jagged teeth on the clamping surface. This clamp tore the sheet, which could have been due to the teeth or the width of the clamp. The width of the clamps was also restricted by the widths of the hospital bed and patient. It was decided that 3 inches would double the width of the second clamp and maximize the amount of space available on both sides of the patient. The clamps are 4 in. long and weigh 3.6 lbs. The dimensional drawings are in Appendix D.

Straps

The polyester straps selected are 1 in. wide and 15 ft. in length with a cam buckle for adjusting the length. The break strength is 1200 lbs. and the working load limit is 400 lbs. To attach the strap, the non-cam-buckle end of the strap is first looped through the eyelet of the clamp. Next, both ends of the strap (cam buckle end and free end) are fed through the gap between the mattress and the headboard. When doing this, the straps must rest on the top roller of the brackets. With both ends of the straps hanging below the bed on the floor, the free end of the strap is looped around the axel of the bed. After being looped and to adjust the length of the strap, the free end of the strap is inserted into the cam buckle. The strap is tightened until it

reaches the desired length. This results in the strap being a closed loop with the free end of the strap coming out of the cam buckle. There is also a wear pad on the cam buckle if the cam buckle is resting on the top of the mattress or any part of the bed to prevent damage to the bed. Figure 5.12 shows the cam buckle.

Figure 5.12. The cam-buckle on the strap.

CHAPTER 6 VERIFICATION ACTIVITIES

6.1. FRICTION CALCULATION

For a past project, the maximum coefficient of friction during the transfer of a patient was calculated. Because the current objective of the proposed device is similar to the objective of the past device, the report can be applied to the current problem. The friction lab report was conducted by the Patient Auto Slider team: Dylan DiGiovanni, Michael Matusiak, Taylor Rieckhoff, and Dan Scheske. The full report is provided in Appendix E. A total of 48 trials were completed at 12 different normal force values; however, 16 trials were eliminated because the normal force value was below 100 lbs. The minimum, maximum, average, and standard deviation of the coefficient of friction were found to be 0.59, 0.72, 0.64, and 0.03, respectively.

Figures 6.1 and 6.2 show the experimental setup and the force gauge setup. Figures 6.3 and 6.4 show the histogram and run chart of the data acquired. Table 6.1 shows the data results.

Figure 6.1. The experimental setup.

Figure 6.2. Force gauge setup.

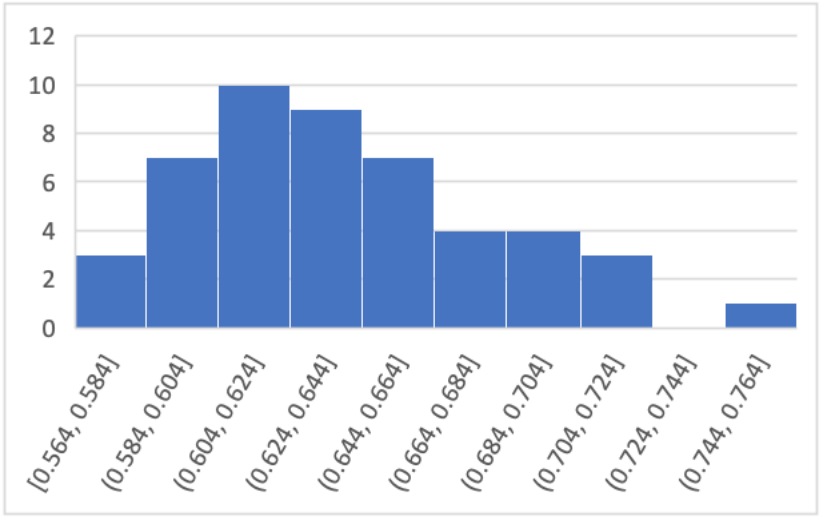


Figure 6.3. The histogram of the data collected in the experiment.

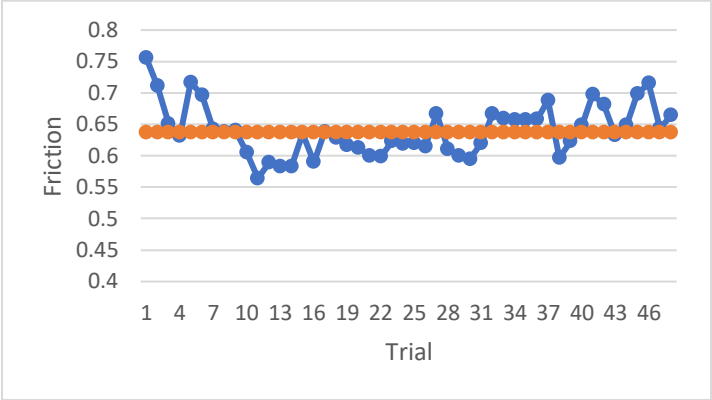


Figure 6.4. The run chart of the data collected in the experiment.

Table 6.1. Calculated values developed from the friction coefficient measured.

Calculated Values Developed from the 32 Friction Values Measured	
Min	0.59
Max	0.72
Standard Deviation	0.03
Average	0.64
Mean + 3 Sigma	0.74

6.2. PULL FORCE CALCULATION

The pull force verification form can be found in Appendix F. The free body diagram can be found in Figure 6.5. F_f represents the frictional force, N is the normal force of the patient, w is the weight of the patient, and F_p is the pull force. The patients boosted are assumed to weigh between 100 and 500 lbs. The range of the friction coefficients is 0.59 to 0.74, as derived from Lab Report 1. The static coefficient of friction was used in all calculations.

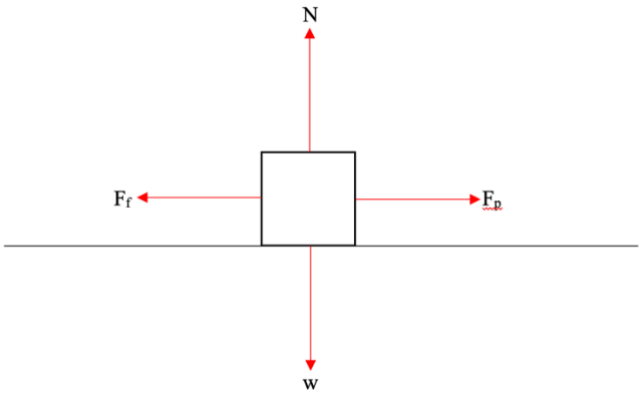


Figure 6.5. The free body diagram of the patient.

The worst-case scenario calculated was a pull force of 156.37 lbs., which includes a patient weight of 500 lbs. and a friction coefficient of 0.74. A friction coefficient of 0.74 means the friction present is high, and there is high resistant when pulling. When the pull force is combined with the weight of the patient, a total of 656.37 lbs. is applied to the hospital bed. The hospital bed's lifting capacity is only 500 lbs. Because of this, the device was designed to be incorporated into a new hospital bed design, one that could support a 500 lb. patient but can lift and or pull 656.37 lbs.

6.3. DEFLECTION CALCULATION

The deflection calculation verification form can be found in Appendix G. The free body diagram can be found in Figure 6.6. The cross-sectional area diagram can be found in Figure 6.7. The deflection was determined using the following equation

$$\delta = \frac{F_p L^3}{3EI} \tag{6.1}$$

where F_p = maximum pull force (lbs.), L = length (in.), E = elastic modulus (psi), and I = moment of inertia (in^4). The bracket is fixed at the bottom. The maximum deflection calculated was 0.045 in. located at the top of the bracket.

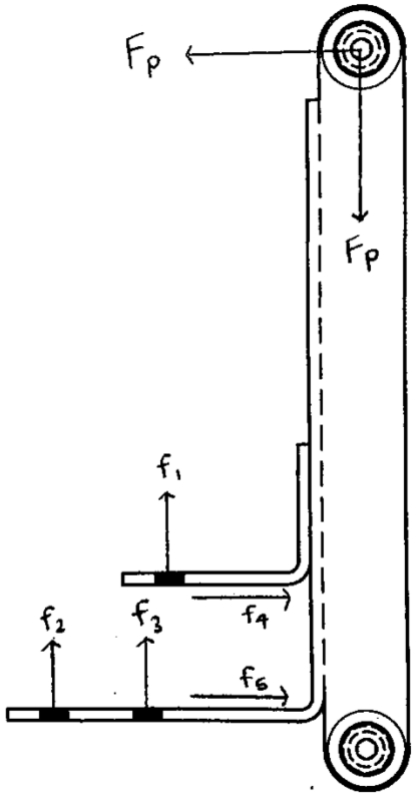


Figure 6.6. The free body diagram of the bracket.

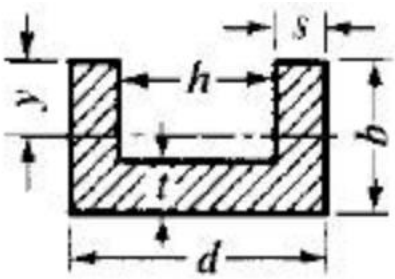


Figure 6.7. The cross-sectional area of the bracket (Engineers Egde, LLC, 2019).

6.4. STRESS CALCULATION

The stress calculation verification form can be found in Appendix H. The thickness of the A-36 steel used in the bracket is 0.125 in. The free body diagram is found in Figure 6.8. It is assumed the bracket is completely fixed at the bottom; thus, the analysis is simplified to a column fixed to the ground.

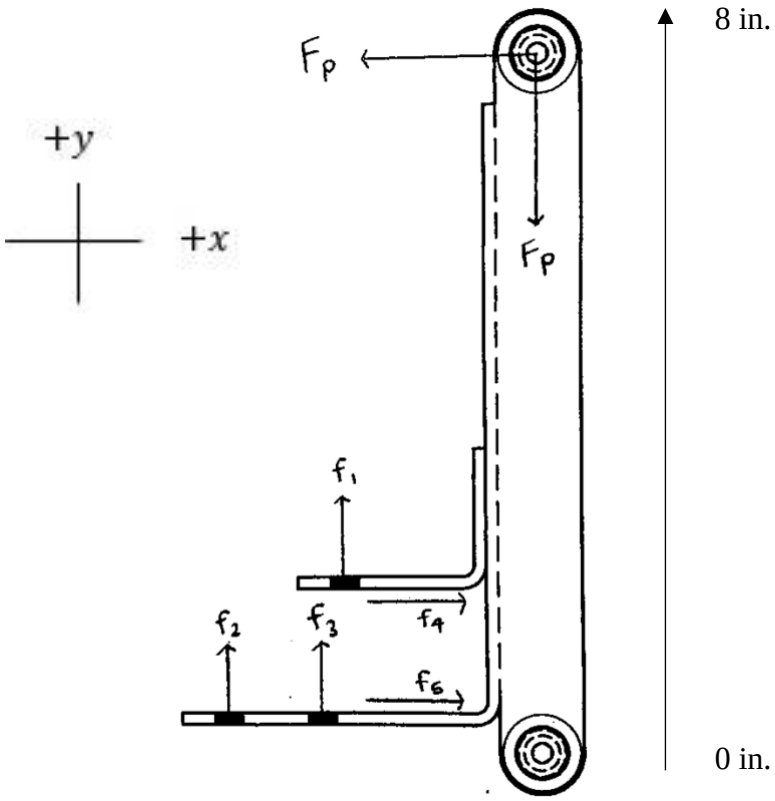


Figure 6.8. The FBD of the bracket.

The compressive stress in the bracket was determined using the following equation

$$\sigma_c = \frac{F}{A} \qquad (6.2)$$

where F = pull force (lbs.) and A = cross-sectional area of the bracket (in^2). The cross-sectional area was calculated to be 0.484 in^2. The compressive stress in the bracket was determined to be 323.1 pounds-per-square-inch (psi).

The bending stress was also determined using the following equation

$$\sigma_b = \frac{My}{I} \qquad (6.3)$$

where M = bending moment (lbs.-in.), y = distance to the neutral axis (in.) and I = moment of inertia (in^4). The bending moment was calculated to be 1250.96 lbs.-in. This was calculated using the pull force from Verification Form #1 and the length of the bracket, 8in. Using the moment of inertia and y value from Verification Form #2, the bending stress was calculated to be 34769.3 psi. The location of the bending stress is located at the bottom of the bracket (0 in.) where it is fixed to the bed. The ultimate strength of A-36 steel is 79800 psi. The safety factor was determined to be 2.30.

6.5 REFERENCES

Engineers Egde, LLC. (2019, April 10). *Moment of Inertia, Section Modulus, Radii of Gyration Equations and Channel Sections*. Retrieved from Engineers Edge Solutions by Design: https://www.engineersedge.com/material_science/moment-inertia-gyration-5.htm#

CHAPTER 7 PROTOTYPE EVALUATION

7.1. FINAL TESTING

A full lab report of the final testing can be found in Appendix I. Testing with the prototype was conducted in the simulation center at CHS every Monday from May to July. The maximum weight pulled was 397 lbs., which exceeds the marginal target of 350 lbs. The distance pulled with the maximum weight was 4.0 inches. The total time of operation was not used as a measurement because each trial lasted the duration of the time it takes the bed to raise from its lowest position to its highest, which is 27.0 seconds. This was done to maximize the potential of the distance pulled. The time it took for the weight to begin to move was recorded. Table 7.1 summarizes the results of testing.

Table 7.1. The results of testing.

Weight Pulled (lbs.)	Distance Pulled (in.)	Time to Start Moving (s.)
63.0	11.0	8.0
271.0	10.0	8.0
397.0	4.0	14.0
417.0	0.0	-

Because the time for the weight to start moving was equal for 63.0 and 271.0 lbs., it is assumed that the quality of the performance of the device was similar. The variation in the distance pulled between 63.0 and 271.0 lbs. could be due to different starting points of the trials. The time for the weight to start moving with 397.0 lbs. was 14.0 seconds, which indicates the quality of the performance was lower than the previous two trials with lighter weight. It was observed that at 397.0 lbs., the weight was pulled in small increments or sudden movements. The trials with less weight had one smooth pulling motion. The sudden movements during pulling

with the 397.0 lbs. is another indication the device could not perform as well as it had with lighter weight.

Another source of variation was the tightness of the straps at the start of each trial. The time to start moving for 397.0 lbs. was 6.0 seconds greater than the two trials with 63.0 and 271 lbs. If the straps had more slack to start the trial with 397.0 lbs., then that is a possible cause for the more significant time to start moving. Because the trial with 397.0 lbs. had visible signs of struggle (sudden movements rather than one pulling motion), it is speculated the tightness of the straps mildly influenced the time to start moving the weight.

The third source of variation was the stretch in the draw sheet. When the straps tightened, the sheet moves before the patient because it is clamped. As testing went on, the stretch in the sheet could have been greater than at the start of testing. The stretch in the sheet would influence the time to start moving similarly to how the tightness of the straps does. The sheet would have to be entirely taught for the patient also to move.

In conclusion, the maximum weight the device can pull is 397.0 lbs.

7.2. STRENGTHS AND WEAKNESSES

There exist several strengths to this prototype. The major strengths include the footprint, simplicity, ability to pull heavy weight, compatibility with beds, and ease of use.

Footprint

Hospital rooms have little space as is, so what is convenient about this device is that it does not add more clutter. The device attaches to the hospital bed without adding width or length to the bed. While in use or storage mode, the device will not be in the way. Additionally, the clamps do not create a large footprint. Off-the-shelf clamps similar to the one designed for this

prototype can be 11 inches in length. The designed clamp is four inches in length, which is significantly less than off-the-shelf clamps.

Simplicity

A frequent complaint discovered in the research phase of the project was that nurses and nurse technicians do not like complicated medical devices. Nurses and technicians want a device that requires minimal steps. This device, once installed, only requires the nurse to attach the clamp to the half sheet and adjusting the straps to the correct length. Once the clamps and straps are set, the nurse pushes the button located at the sides or the foot of the bed to raise it. Additionally, the device itself is composed of three parts that do not require thorough training to use or adjust.

Ability to Pull Heavy Weight

The device can pull 397.0 lbs. as concluded from testing. The device was tested without using a friction-reducing agent, such as a PATRAN sheet. The device allows one nurse to pull a large patient that would typically require a minimum of three people to boost.

Compatibility with Beds

The device was retrofitted to an available hospital bed at CHS. Although hospital beds can vary based on the model, the brackets could be adjusted in size to fit. The clamps and straps would not have to change from bed to bed. The device also does not impede the range of motion of the bed.

Ease of Use

The operation of the device is as easy as the push of a button. Operating the device is quickly learned and remembered because it relies on the hospital bed that nurses know how to use and use every day.

The current concerns of the device are containing the straps, the strap material and the longevity of the device.

Containing the Straps

Currently, the straps do not contract into a storage unit. If and when the device is not in use, the straps could potentially drag on the ground. Uncontained straps pose a potential hazard because the straps could get caught on the wheels of the bed or the feet of people in the room.

Strap Material

The material of the straps is polyester, which is not easily disinfected. This could create problems when using the straps for different patients if not properly washed in between uses.

Longevity of the Device

The device itself is made of steel; thus, the components of the device are not of concern. The hospital bed repeatedly being used under heavy load is the concern. The condition of hospital beds can vary widely from hospital to hospital and even within one hospital. Relying on the hospital bed's power could reduce the lifetime of the hospital bed, especially with this device performing an action that can happen at least 30 times a day. The total force needed to boost a patient with this device is 656.37 lbs., which is bigger than the capacity of a hospital bed. Thus, the device should be used as an incorporation to a new hospital bed design not to overexert the existing hospital bed.

7.3. PATENT SEARCH

Table 7.2 summarizes prior art related to boosting patients. The keywords used in the patent search were boosting patients, boost a patient, repositioning a patient, sliding a patient and roller bracket. The only patent expired is the one that was filed on September 27, 1989. The four patents documented are the patents that possess similarities to the device. There is a multitude of

patents filed for patient handling; however, those patents do not possess similarities to the device prototyped.

Table 7.2. The summary of prior art.

File Date	Patent No.	Inventor(s)	Description	Similarities	Source
21-Dec-05	US 7487,558 B2	James R. Risk Jr., David W. Williams, Matthew C. Visca., Peter M. Wukusick, James K. Findlay, Robert M. Zerhusen	A headboard or an attachment to a headboard that has a retractable strap. The headboard has a roller on top and the straps are attached to the draw sheet by a clamp.	The device uses a strap and clamp to attach to the draw sheet. The strap is retracted into a unit to pull the patient.	(United States of America Patent No. US7487558B2, 2005)
27-Sep-89	5,005,231	Robert Lonardo	A large pad with straps.	Straps are used to pull the patient.	(United States of America Patent No. 5005231, 1989)
29-Jun-01	US 6,560,793 B2	Lucinda B. Walker	A low friction draw sheet with straps.	Straps are used to pull the patient.	(United States of America Patent No. US6560793B2, 2001)
15-Mar-13	US 9.205,012 B2	William A. Hillenbrand II, Timothy Savage, Joseph Kummer, Dale Foster, Jeffrey Woodall, Andrew Rogier, Antonio J. Belton	A drive mechanism underneath the mattress that is attached to the frame of the bed that pulls a strap. The strap is connected to a sheet.	A strap is used to pull the patient. Attaches to frame of the bed.	(United States of America Patent No. US9205012B2, 2013)

Patent US 7487,558 B2 is a headboard attachment or replacement that consists of a roller, straps and clamps. This device is shown in Figure 7.1 (United States of America Patent No.

US7487558B2, 2005). The clamps are used to attach to the draw sheet. The roller is on top of the headboard piece and assists the straps in retracting. The straps are retracted into a container using a drive mechanism (United States of America Patent No. US7487558B2, 2005). The proposed device is similar to this patent by both using clamps and straps; however, the patent claims a headboard is used to pull or retract the straps. The proposed device does not use a headboard or anything similar to a headboard.

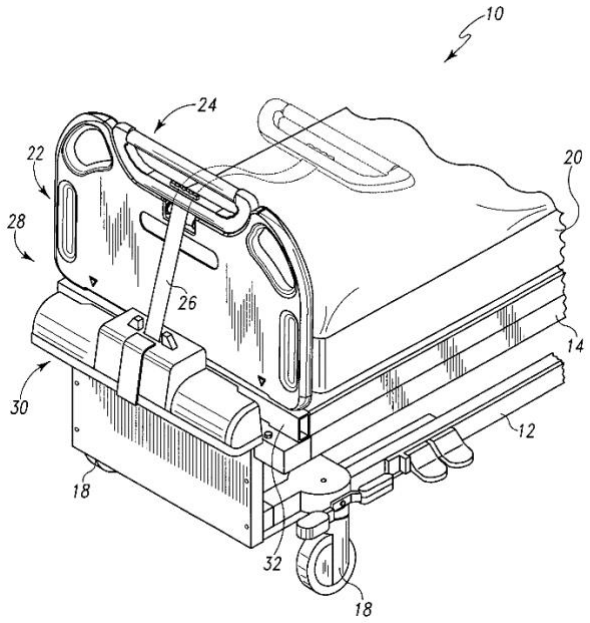


Figure 7.1. The device described in Patent US 7487,558 B2.

Patent 5,005,231 is a sheet with continuous straps through the middle and on the edges. Figure 7.2 shows the device described in Patent 5,005,231. The patent claims this device is used to reposition patients with the pad and transverse straps (United States of America Patent No. 5005231, 1989). The proposed device is similar to this patent by requiring straps; however, the patent claims a pad with straps that goes under a patient. The proposed device does not require an external pad to fit under the patient.

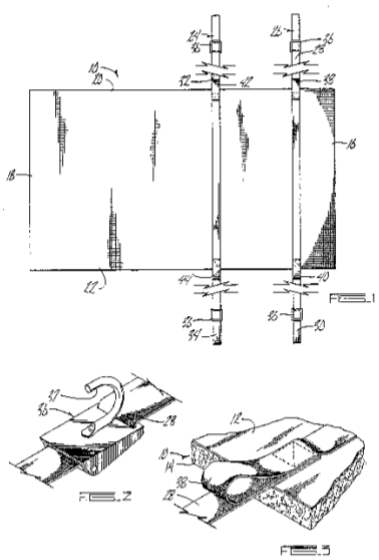


Figure 7.2. The device described in Patent 5,005,231.

Patent US 6,560,793 B2 is a draw sheet with side rails. Figure 7.3 displays the device for Patent US 6,560,793 B2. The patent claims that this device can reposition or turn patients by wrapping a strap around the side rails and patient (United States of America Patent No. US6560793B2, 2001). What is similar about this patent and the proposed device is that a draw sheet is required. The proposed device utilizes the existing draw sheet that is placed on every hospital bed; however, the device in patent US 6,560,793 B2 is a modified draw sheet that would have to be placed underneath the patient.

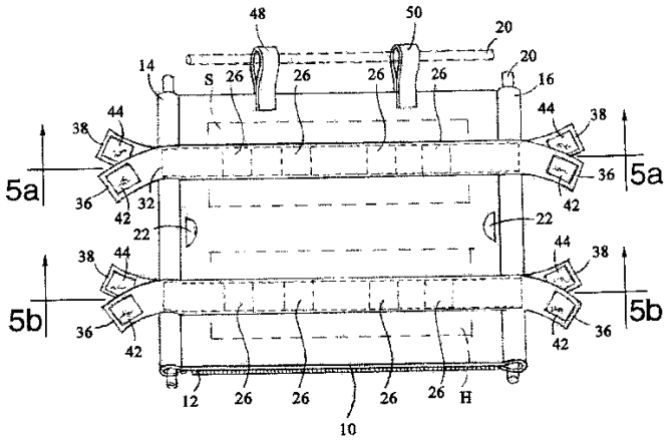


Figure 7.3. The device described in Patent US 6,560,793 B2.

Patent US 9.205,012 B2 is a mattress, drive mechanism and sheet. Figure 7.4 displays the device in Patent US 9.205,012 B2. This patent claims to use a mattress on a plane with a sheet on the upper surface and a drive mechanism on the lower surface (United States of America Patent No. US9205012B2, 2013). The proposed device is similar to this in that it uses a mattress and a sheet on the top surface of the mattress. The patent also claims the drive mechanism connects to the sheet and pulls the sheet toward the head of the mattress (United States of America Patent No. US9205012B2, 2013). The proposed device does this action but without an external drive mechanism.

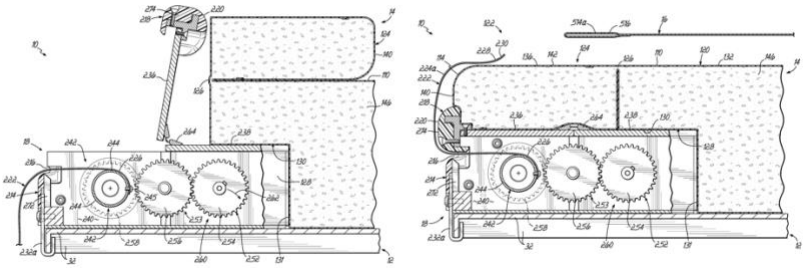


Figure 7.4. The device described in Patent US 9.205,012 B2.

What makes the device innovative is that it utilizes the hospital bed, has only three components, does not require manual force, and does not rely on an attached external power source. Two devices mentioned in Table 7.1 rely on a mechanism that retracts and pulls straps, while the other two rely on a person to manually pull on the straps to move the patient. The second and third patents of Table 7.1 also would require the devices to be placed underneath a patient, which is counterproductive to those devices. Although the patents discovered may also be easy to use, more than three components are required, or the device could always not be on the bed. This is where the proposed device differs. The proposed device can stay on the bed and is retrofittable to beds without creating a large footprint.

The prototype developed has the potential to be patented. The brackets paired with the clamps create a unique solution to the problem presented that differ from existing patents. Other devices that do not require an external power source are variations of sheets with straps or do not utilize the bed's mechanics, which would not interfere with this device. Additionally, the design of the brackets and the clamps, individually, are unique to existing products on the market as well.

7.4. REFERENCES

Hillenbrand II, W. A., Savage, T., Kummer, J., Foster, D., Woodall, J., Rogier, A., & Belton, A. J. (2013). *United States of America Patent No. US9205012B2.*

Lonardo, R. (1989). *United States of America Patent No. 5005231.*

Risk Jr., J. R., Williams, D. W., Visca, M. C., Wukusick, P. M., Findlay, J. K., & Zerhusen, R. M. (2005). *United States of America Patent No. US7487558B2.*

Walker, L. B. (2001). *United States of America Patent No. US6560793B2.*

CHAPTER 8 CONCLUSIONS

8.1. FUTURE IMPROVEMENTS

Looking ahead, several improvements could be made to the device. The first improvement would be to manufacture the clamps out of aluminum or another material with an excellent strength-weight ratio. The current material of the clamps is steel, so changing to aluminum could reduce the weight of each clamp. An additional change to the clamp could be mimicking a vise grip. Figure 8.1 shows the adapted vise grip that was briefly tested. Developing a clamp similar to the one shown in Figure 8.1 could reduce the cost of the clamp and also the weight. The vise grip clamp would have an eyelet, as shown in Figure 8.1, instead of an adjustment screw.

Figure 8.1. The vise grip adaptation clamp.

Another change to the device would be to find a set of straps made of low friction and washable material. The current material of the straps is polyester, which is not an ideal material for hospitals due to the inability to wash it easily. Having a low friction material would also help the strap travel while tightening.

A third improvement would be to design a housing unit for the straps to retract. This would eliminate the concern of a person tripping on the straps or the wheels of the bed getting caught. The storage phase of the device would be more compact, as well.

Overall, the device provides a simple and effective method of boosting patients. The needs to pull an obese patient with only one operator and to have a small footprint were met. The device provides numerous benefits such as eliminating manual labor, using the hospital bed, and having minimal operating steps. With the elimination of manual labor, the device can potentially reduce injuries to nurses, which would reduce costs for hospitals. It was hypothesized that a cost-effective solution did not exist in the market for boosting patients. This gap in the market is characterized as a device that requires minimal manual force and has a lower cost than a fully automated device. Because this device does not require manual force and has only three components, it fills the gap. This device is a unique, cost-effective solution to the ongoing problem of boosting patients.

8.2. NEXT STEPS

The possible next steps of this prototype are to incorporate the improvements mentioned in section 8.1, solidify the design, and file for a provisional patent. Because the device provides an innovative solution, a provisional patent seems plausible. The device should be incorporated into the design of hospital beds, given the lifting and pulling requirements to boost a patient with the device. Hill-Rom and Stryker are two bed manufacturers that could be contacted to pursue this device further. Hospital systems, such as Beaumont, Spectrum Health, or Sparrow Health, are also an option to contact.

Bill of Materials

The components were fabricated and supplied by C.L. Rieckhoff Co., Inc. The bill of materials includes the cost for the prototype and an estimate for production cost. The full Bill of Materials can be found in Appendix J.

In the value analysis, the potential manufacturing revenue per device was about $9,687.71. The total cost for the components used in the final prototype (the 2” bracket, strap, and the machined clamp) was $417. Using the provided production run estimates, the cost of the device without the straps is $170. The straps were not included in the production run estimates because they were an off-the-shelf component and not fabricated. The manufacturing cost of components generally decreases when the volume of components increases. Both the production estimate and the actual prototype cost are significantly less than the estimated manufacturing revenue from the value analysis.

Appendix A: Interviews

Full Interview Results

Grand Valley State University Faculty

1. Who is doing the boosting the most often?
    a. Varies depending on the setting: Technicians in assisted living, nurses and technicians in acute care, OT or PT in rehab center.
    b. 90% of the time nursing assistants
    c. Nurses and technicians
2. What type of patients need the most boosting?
    a. Patients in the medical surgical unit
    b. Immobile (disabled, incapacitated, coma, brain injury), stroke patients, whole body system failure patients
    c. Obese, restless (gravity pulls them down), patients in pain (right out of surgery or an injury restricting movement), immobile
3. What is the suggested method?
    a. Patient bends knees, one person on each side, grab half sheet and pull
    b. Draw sheets, two people, put the head of the bed down
    c. Bed at level to not bend down, lift with legs, draw sheet, one person on each side, head of the bed down
4. What is the common/real method?
    a. Don't wait for enough help or the patient might not get boosted
    b. May not always use the draw sheet, lift under shoulders or armpits, use two people

    c. Same as the suggested method

5. How many people are usually required to boost a patient?
    a. Extended care: one sometimes, otherwise should be two
    b. Two used, less than two used only if the patient can help
    c. Two at the minimum (hard with obese patients and there are a lot of obese patients), add more if needed
6. How often do nurses boost patients?
    a. Primarily in bed: every two hours, multiple times a shift
    b. Assuming immobile: two to four hours, if the patient can support themselves: less often
    c. Differs per patient. As needed. Sometimes the patient doesn't know they're uncomfortable.
7. Where is the boosting most often done?
    a. Medical Surgical, Elderly, Ortho trauma, people who have chronic issues with mobility (long term care)
    b. See question 2.
    c. Everyone potentially/anyone on beds. Patients that are frail, obese, or painful.
8. How often do nurses hurt themselves from boosting?
    a. Less than they used to
    b. All the time, more often than not
    c. If they use good body mechanics, not often but it can happen a lot
9. Are there any tools, devices, or products commonly used? Are they well liked?

a. Ceiling lifts, Hoyer lifts, sit to stand lifts. They require time and knowledge. There is room for improvement.
b. Draw sheet, pull the whole sheet, Hoyer lift. No preference.
c. Draw sheet. A draw sheet has just always been used/no preference.

10. Is there an ideal product you have in mind to help with boosting?
    a. Something you don't have to run and get, a pad that has little rollers, something like a furniture slider pad
    b. It would be nice if the patient didn't slide down as much. A conveyor belt around the bed.
    c. Velcro under the patients' butts, something mechanical at the head of the bed that hooks on to the sheet and pulls without the sheet sliding out from under the patient

Full-time, Registered Nurses

1. How often do you boost patients?
    a. Every two to four hours during shifts
    c. Patients who can't move themselves usually get scooted up about every four to six hours.
    d. As often as needed. Every two hours is routine for positioning.
2. How many people are required?
    a. One to four
3. What is your method of lifting patients up in bed?
    a. Sliding sheets most commonly, turning sheets, moving slings

b. They normally have a sheet we call a lift sheet under them, so we grab on to that and slide them up after putting the head of the bed down. Usually the lift sheet is the only way they tell us to it. They sometimes recommend tilting the bed like upside down a little for gravity, but we don't.
c. Usually when they slide down, we use a sheet to lift them back up.
d. We have an incontinence pad, or we use a sheet depending on the facility. There are also sliding/gliding pads.

4. What departments need the most boosting?
    a. Adult medical surgical, adult cardiac and adult bariatric. Probably all geriatric units.
5. Have you seen or heard or gotten injured from doing this?
    a. Yes. Not me personally but my body probably has some residual effects from poor/strained lifting and other nurses have thrown out disks in their backs, pulled muscles, etc.
    b. Yes, constant back strain.
    c. Yes, most of the nurses I know over 50 have some sort of back or shoulder injury.
6. What would be your ideal product to use for this instead of manually lifting?
    a. A sheet that the patient lays on that could be hooked and unhooked from a crane above the patient's bed. Boost them all with the touch of a button.
7. Do you ever just lift them yourselves? Without a sheet just with your hands?
    a. Yeah sometimes but it doesn't work very well
    b. Little kids you can lift alone, otherwise you use the draw sheet and get help.

c. Yes, sometimes I feel like they could be uncomfortable but, in the end, I think they are ok with it because they understand we are there to help not harm. I do wish that there were more options or that more rooms have lifts from the ceiling to protect healthcare professionals from injury.

Appendix B: House of Quality

Table B1. The Interpreted Needs of the House of Quality.

Group Name	Customer Quotes	Importance Rating	Interpretted Need
Patient Characteristics	Immobile (disabled, incapacitated, coma, brain injury), strokes, whole body system failure	4	The device moves the patient safely
	Obese, restless, painful patients, immobile	4	The device moves the patient safely
	Med. Surg. Patients	4	The device moves the patient safely
	Elderly, Med. Surg. Department, ortho trauma department, people who have chronic issues with mobility	4	The device moves the patient safely and is compatible with multiple beds
	Adult Med. Surgical, adult cardiac and adult bariatric. And probably all the geriatric units	4	The device moves the patient safely and moves heavy patients
	Patients are heavy and getting heavier	4	The device moves heavy patients
Occurrence	Every 2-4 hours during shifts	5	The device needs to be reliable and quick to use
	Happens as often as needed, it's for comfort and to prevent falls and to prevent pressure ulcers. Like every 2 hours is routine for positioning.	5	The device needs to be reliable and quick to use
	Patients who can't move themselves usually get scooted every 4-6 hours.	5	The device needs to be reliable and quick to use
	(Patients) primarily in bed, every 2 hours. Multiple times a shift.	5	The device needs to be reliable and quick to use
	Assuming immobile, 2-4 hours. If a patient can support themselves, less often.	5	The device needs to be reliable and quick to use
	As needed	5	The device needs to be reliable and quick to use
Method	1-4 people are required. Sliding sheets most commonly, turning sheets, moving slings	4	The device should be operated by 1 person
	They normally have a sheet we call a lift sheet under them do we grab on to that and slide them up after putting the head of the bed down	4	The device should limit the manual labor
	Usually when they slide down we use a sheet to lift them back up.	4	The device should limit the manual labor
	We have an incontinence pad or use a sheet depending on the facility. There are also sliding/gliding pads.	4	The device should be readily available and cost effective
	Patient bends knees, one person on each side, use turning pads to put draw sheet or sliding sheet underneath, pull patient up. Should be 2 people.	4	The device should be operated by 1 person and quick to use
	Draw sheet, 2 people, head of the bed down then slide	4	The device should be easy to use
	Bed at level to not bend down, head of bed down, draw sheet, one person on ecah side, lift with legs, 123 pull.	4	The device should be quick to use
	Lower bed, grab sides of sheet, 2 people, count down and pull. A lot of adjusting afterward.	4	The device should be operated by 1 person
Opinions on Current Tools	Requires time and knowledge	4	Intuitive
	I don't remember/know how to use this.		
	I do wish that there were more other options or that more rooms had lifts form the ceiling to protect us.	5	Little to no human power
Other	35 lbs. lifting maximum	5	Little to no human power
	Available lift is anywhere from 150 to 550 ft away.	4	Readily available for multiple uses a day

Table B2. The Engineering Characteristics of the House of Quality.

#	Interpreted Need	Engineering Characteristic	Units
1	The setup needs to be simple.	Steps prior to boost	Number of steps
2	The boosting process can be executed quickly.	Boost time	Seconds
3	Quick to disassemble.	Take-down time	Seconds
4	Minimal people required for operation.	Number of operators	Number of people
5	Compatible with beds.	Percent of compatible beds	Percentage
6	The device moves large patients.	Weight of the patient	lbs.
7	The device moves the patient safely.	Success rate of patient being moved safely	Percentage
8	The device operates normally after repeated use.	Lifecycle	Number of uses
9	The device reduces manual labor for user.	Amount of weight pulled by the user	lbs.
10	The device is cost effective.	Manufacturing cost	Dollars
11	The device completes the transfer fully.	Max distance pulled	in./ft.
12	The device is quiet.	Sound pressure level	dB

Table B3. The QFD Chart in the House of Quality.

	Interpreted Need / Engineering Characteristics	**Importance Rating (5,4,3,2,1)**	Steps to operate	Patient moving time	Take-down time	Number of operators	Percent of compatible beds	Weight of the patient	Success rate of patient being moved safely	Life of Machine	Amount of weight pulled by the user	Manufacturing cost	Max distance pulled							
	Improvement Direction		↓	↓	↓	↓	↑	↑	↑	↑	↓	↓	↑							
	Interpreted Need																			
Setup/tear down	The setup needs to be simple	5	+				-													
	Quick to disassemble	4			+		-													
	Compatible with beds	5					+													
	The device should be cost effective	3								-		+								
	The device completes the transfer fully	4							+				+							
Boost	Minimal people required for operation.	4	-	-	-	+			-		-									
	The boosting process can be executed quickly.	5		+		+		-	-											
	The device is able to move large patients.	4				+		+			+									
	The device reduces manual labor for user	4									+									
Safety	The device moves the patient safely	5							+											
	The device operates normally after repeated use	5							+	+										
	Organizational Difficulty (Scale of 1-5)		3	2	4	4	3	4	3	4	4	3	3							
	How Much/Target Values		Ideal: 3 Marginal: 5	Marginal: 2.5<x<6 s Ideal: 3<x<5 s	Marginal: 30 s Ideal: 20 s	Ideal: 1 Marginal: 1	Ideal: 90% Marginal: 80%	Marginal: 350 lbs. Ideal: 500 lbs.	Ideal: 100% Marginal: 100%	Marginal: 21,900 Ideal: 43,800	Marginal: 35 lbs. Ideal: 0 lbs.	Marginal: $7,000 Ideal: $5,000	Ideal: 13 in. Marginal: 8 in.							

Table B4. The justifications for the specifications in the House of Quality.

#	Engineering Characteristic	Units	Ideal and Marginal Targets	Justification for Ideal and Marginal target values?
1	Steps to operate	Number of steps	Ideal: 3 Marginal: 5	The current manual process requires 7 steps.
2	Patient moving time	Seconds	Marginal: 3<x<6 s Ideal: 2.5<x<5 s	During the manual boosting process, the patient is physically being moved for roughly 2-3 seconds. The manual process is abrupt, thus, to create safer conditions for the patient the moving time can be slower with the device.
3	Take-down time	Seconds	Marginal: 30 s Ideal: 20 s	The time to take down the device should be minimal given. If the device takes too long to take-down, the appeal of the device decreases.
4	Number of operators	Number of people	Ideal: 1 Marginal: 1	The current, manual boosting process that is the most common takes a minimum of 2 people. If the weight of the patient exceeds 240 lbs., then at least 3 people are required to move the patient. The people required to use this device should be one in order to increase the economic feasibility of the device.
5	Percent of compatible beds	Percentage	Ideal: 90% Marginal: 80%	In one hospital building the style of bed can change from each department. From hospital to hospital, the brand and style can change. Marginally, the device should operate successfully on 80% of the hospital beds on the market which are Hill-Rom or Stryker. Ideally, the device would work for almost any bed whether it is Hill-Rom/Stryker or not.

6	Weight of the patient	lbs.	Marginal: 350 lbs. Ideal: 500 lbs.	The weight of American adults is on the rise. Patients have a large range of weight, so the device should be able to operate for the maximum weight outside of the bariatric unit. Bariatric patients weigh 350 lbs. or greater (Muir & Archer-Heese, 2009). Ideally, the device could work for more than 350 lbs. and work for the 500 lb. capacity of the hospital bed.
7	Success rate of patient being moved safely	Percentage	Ideal: 100% Marginal: 100%	The patient should be successfully, safely, and comfortably moved every time the operation occurs.
8	Lifecycle	Number of uses	Marginal: 21,900 Ideal: 43,800	Assuming patients are boosted 20 times a shift by one nurse, the device would be used for 4,380 boosts in one year. The device should last for at least 5 years and ideally it would last 10 years. The device should have to have minimal maintenance in a 5-year span, and not be replaced until at least 5 years of use.
9	Amount of weight pulled by the user	lbs.	Marginal: 35 lbs. Ideal: 0 lbs.	A nurse is required to be able to lift up to 35 lbs. A nurse is not allowed to lift more than 35 lbs., otherwise another person or a device is required to complete the task at hand. The device should minimize the amount of weight the user must pull/lift. Ideally, the device should be fully automated so the operator does not have to lift or pull any weight.
10	Manufacturing cost	Dollars	Marginal: $7,000 Ideal: $5,000	The total potential value per device was calculated to be $167900. The manufacturing cost is projected to be 25% of the total value. Ideally, the manufacturing cost would be low without reducing quality.

				The value analysis is described below.
11	Max distance pulled	in.	Ideal: 13 in. Marginal: 8 in.	The current, manual boosting process moves a patient anywhere from 6 to 12 inches depending on the patient and how far down the bed he/she has moved.
12	Sound pressure level	dB	Marginal: 45 dB Ideal: 0 dB	45 dB is the sound level that is louder than a whisper but quieter than a normal conversation (Dima, 2017).

Table B5. The analysis of the House of Quality.

#	Engineering Characteristic	Units	Strongly Correlated Interpreted Need(s)	Other Engineering Characteristics that are Strongly Positively or Negatively Correlated (Roof Data)	What does this mean for the design team?
1	Steps to operate	Number of steps	The setup needs to be simple (+) and minimal people required for operation (-)	Number of operators (SP) and percent of compatible beds (P).	Keeping the number of operation steps at a minimum will be crucial. The device should be simple enough where one person is only required and the device is easy to use, but not too simple where it is less compatible for beds.
2	Patient moving time	Seconds	Minimal people required for operation (-) and the boosting process can be executed quickly (+).	Weight of the patient (N) and Success rate of patient being moved safely (N).	The patient should be moved quickly enough to save nurses' time, but not too quickly to hurt or endanger the patient. The device needs ot be designed to complete the job in an orderly and safe matter.
3	Take-down time	Seconds	Quick to disassemble (+) and minimal people required for operation (-).	Number of operators (SN).	The take down time needs to be quick and simple to optimize the users' time. If the device is not designed to be taken down quickly, the appeal

					of the device decreases.
4	Number of operators	Number of people	Minimal people required for operation (+), the boosting process can be executed quickly (+) and the device is able to move large patients (+)		The device needs to be designed where it is simple and easy enough to use by one person. This will be better than current methods and also save time and energy for nursing staff.
5	Percent of compatible beds	Percentage	The setup needs to be simple (-), quick to disassemble (-) and compatible with beds (+).	Manufacturing cost (N).	The design should be compatible for Hillrom and Stryker beds which are the two most common brands of hospital beds sold. If the device can operate successfully on these two brands of beds, then majority of the market will be covered.
6	Weight of the patient	lbs.	The boosting process can be executed quickly (-) and the device is able to move large patients (+).	Amount of weight pulled by the user (P).	The design of the device should be able to withstand large patients, which means the device needs to durable and adjustable.
7	Success rate of patient being moved safely	Percentage	The device completes the transfer fully (+), minimal people required for operation (-), the boosting process can be executed quickly (-), the device moves		The patient's safety is the number one priority. The device should not compromise the patient's safety to any degree. The device should include a factor of safety, be durable and be fail safe. (If

			the patient safely (+) and the device operates normally after repeated use (+).		the device does fail for any reason, the user and the patient should not be harmed or endangered.)
8	Lifecycle	Number of uses	The device should be cost effective (-) and the device operates normally after repeated use (+).		The device needs to be durable and robust enough to last at least 5 years. The device should be tested thoroughly to manage the design and add improvements before the finished prototype is made.
9	Amount of weight pulled by the user	lbs.	Minimal people required for operation (-), the device is able to move large patients (+) and the device reduces the manual labor for user (+).		The design should account for the nurses' lifting limit of 35 lbs. and ideally not require any weight pulled by the user.
10	Manufacturing cost	Dollars	The device should be cost effective (+).		The manufacturing cost of the single prototype should be minimized. The potential manufacturing cost for mass production should be considered when designing the device.
11	Max distance pulled	in./ft.	The device completes the transfer fully (+).		The design needs to be able to pull the patient up to the desired location.

\

Appendix C: Brainstorming Procedure

Procedure

1. Present the problem

   Direct care employees sustain injuries from boosting patients. Boosting a patient is when a direct care employee lifts/pulls a patient up in bed after the patient has slid down. This action occurs anywhere from 10 to 30 times a shift. The current method involves a minimum of two direct care employees (more if the patient is larger) grabbing the draw sheet on the bed and manually pulling the patient up.

2. Rules
   a. Pursue quantity first
   b. No criticism or judgment
   c. No evaluation
   d. There are no "bad ideas"
   e. Build off of each other's ideas

3. Procedure explanation
   a. The warm-up exercise will be performed first. This is to get your mind and ideas flowing and to bring out your creativity. There are two possible warm-up activities.
   b. After the warm-up, the participants will sit in silence for 2 minutes to collect thoughts and get in the zone for brainstorming the problem.
   c. Brainstorming the problem will involve focus for the allotted time. There are three brainstorming methods selected for three different group sessions.
   d. The ideas will be shared, discussed, collected and processed.

4. Warm-Up exercise
    a. Paperclip

    The participants will be asked to come up with as many ways to use a paperclip as possible.

    b. Bad Ideas

    The participants will each get an absurd or impossibly ineffective idea (cardboard umbrella, orange juice-flavored toothpaste, etc.). Each participant will have to come up with as many advantages as possible for the idea. The participants will then have to pitch their idea to the group.

5. Silent period

    The participants will get 2 minutes of silence to prepare their minds for brainstorming the problem.

6. Brainstorm problem solutions
    a. Brain Dump (Individual Session)
        i. Critical sub-functions (move patient, secure patient and apply force) are identified
        ii. A timer is set for two minutes while participant writes out ideas for each sub-function on slips of paper, one idea per paper. Two minutes per sub-function.
        iii. Participant searches brain for 10 minutes writing out a list of ideas to the sub-functions.
        iv. Participant completes a 20-minute internet search using Google Images, home improvement/industrial supply websites, and Google Patents.

b. Crawford Slip Method (Non-Engineering Session) (Dettmer, 2003)

   The facilitator creates target or focus statements for the participants. The participants write replies to these target statements on slips of paper, one idea per slip. After the participants finish, the facilitator performs data reduction by eliminating identical ideas. Then, the ideas are collected and categorized.

c. Mitsubishi Method (Professor Session) (Tatsuno, 1990)

   The problem is identified for the participants. The participants write down their solutions. When everyone has finished writing, the ideas are read aloud. Those with no or only a few original ideas can piggyback ideas and read them aloud with their own ideas. The ideas are explained aloud in detail and an idea map is drawn. Ideas are discussed and evaluated.

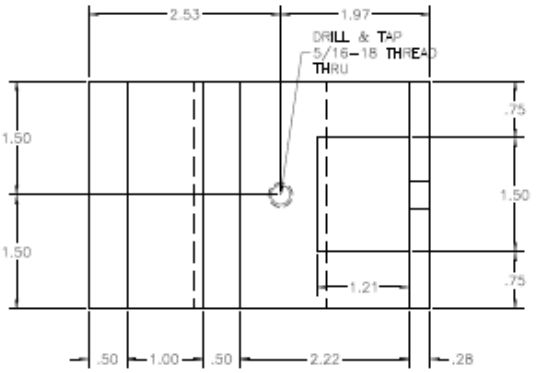
d. NHK (Hiroshi Takahashi) Method (EGR 401 and 503 Sessions) (Tatsuno, 1990)

   In response to a problem statement, participants write down five ideas on separate cards. Participants meet in groups of five. Each person explains ideas to other members of group. Other members write down any new ideas that come to mind on separate cards. The cards are collected and sorted into groups by theme. New groups of two/three people are formed. Each group takes one or more of the sorted group of cards and brainstorms for new ideas. Each group organizes its cards by theme and announces ideas to rest of the group. All ideas are written on a large surface by a leader or recorder.

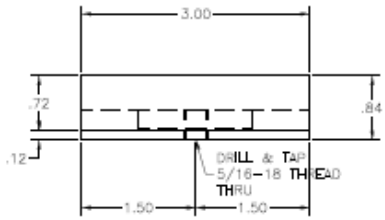
7. Process Ideas

After the group ideation session(s), the ideas will be documented and organized as appropriate. The ideas will be analyzed and combined if necessary, to create meaningful concepts to solve the problem.

Appendix D: Dimensional Drawings



TOP VIEW



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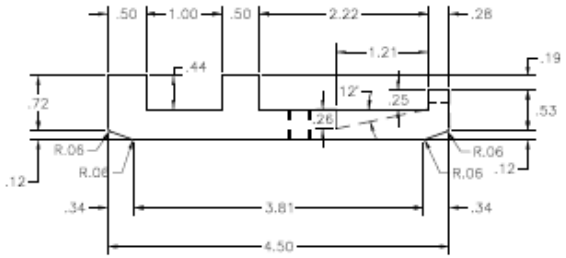
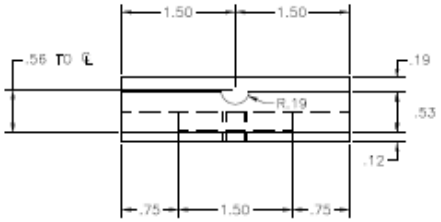


SIDE VIEW



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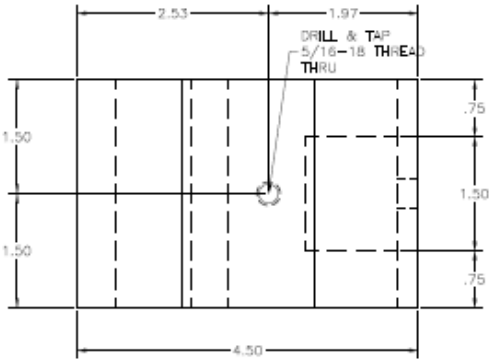
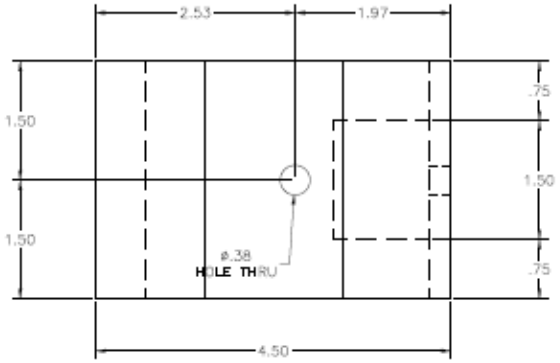


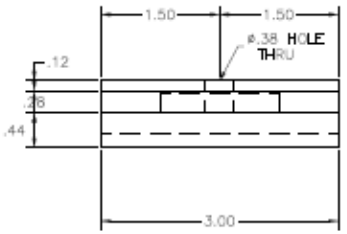
BOTTOM VIEW

(TWO) BOTTOM CLAMP

1 GENERAL REVISIONS 06-06-2019



TOP VIEW



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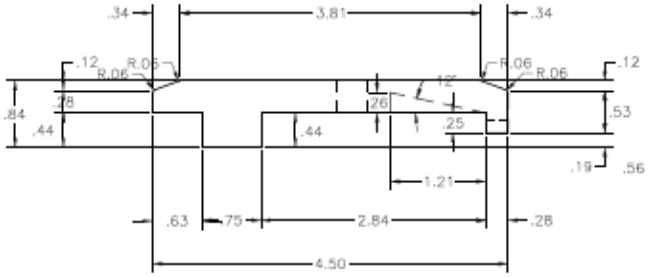
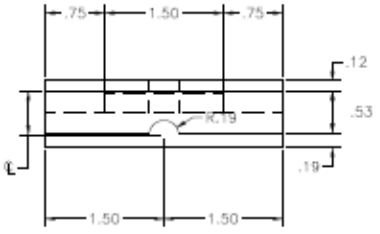


SIDE VIEW



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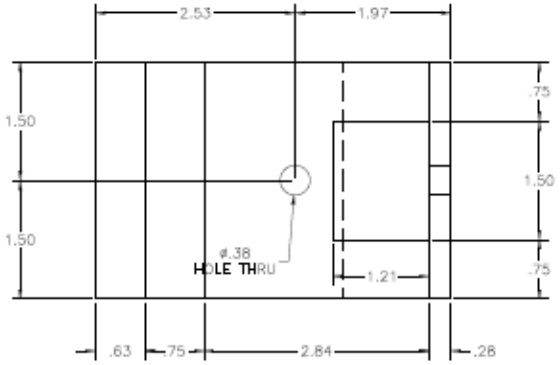


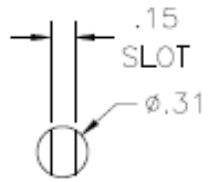
BOTTOM VIEW

(TWO) TOP CLAMP

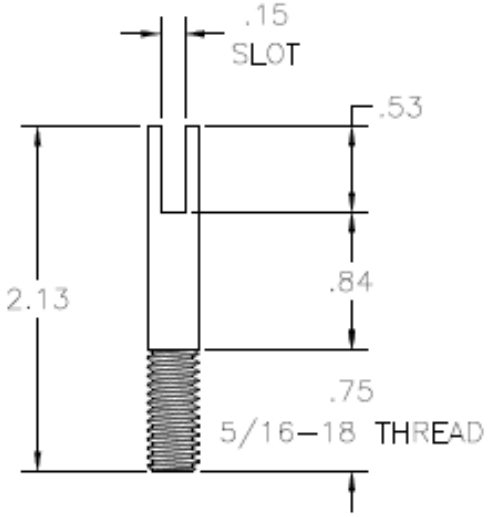
1 GENERAL REVISIONS 06-06-2019

(TWO) ETCH

10 GAUGE HR 1 7/8" x 2 7/8"
LASER CUT

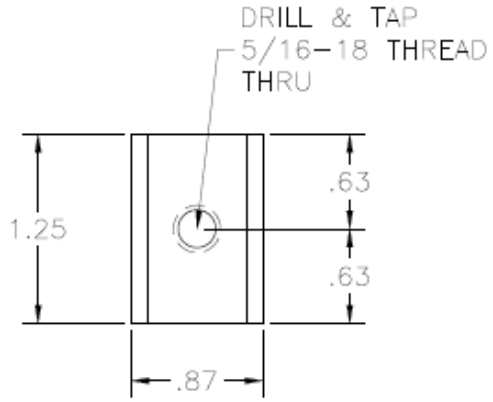


TOP VIEW

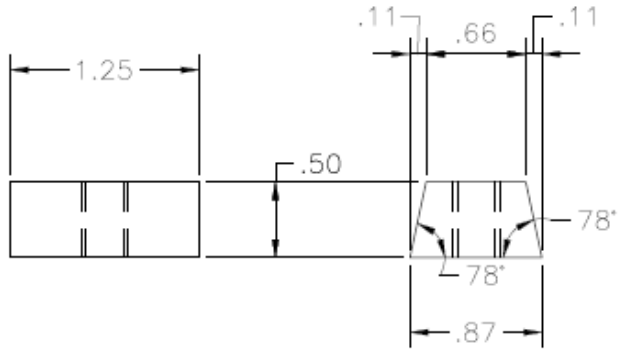


SIDE VIEW

(TWO) RODS



TOP VIEW

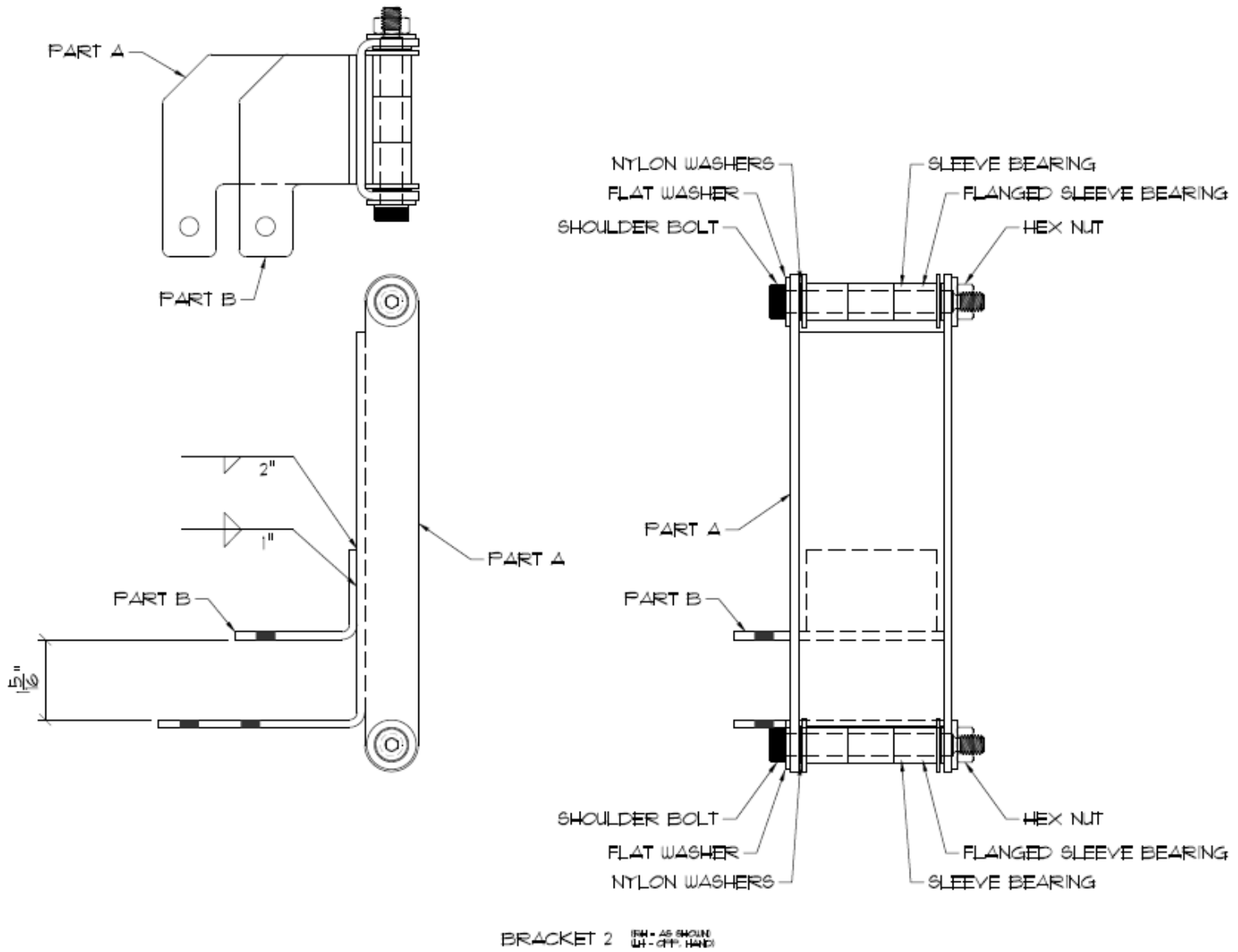


END VIEW SIDE VIEW

(TWO) SLIDE NUTS

1 GENERAL REVISIONS 06–06–2019

BRACKET 2 PART B
10 GAUGE HR 3 3/16" x 3 5/16"
LASER CUT
2 RH AND 2 LH REQUIRED OF EACH PART
BRACKET 2 PART A
10 GAUGE HR 4 1/16" x 10 7/32"
LASER CUT
DOWN 90°
UP 90°



BRACKET 2 RH = AS SHOWN LH = OPP. HAND

Appendix E: Friction Lab Report

Determination of Friction Coefficient in a Hospital Draw Sheet During Patient Transfer

By

Patient Auto-slider Team, Grand Valley State University

Executive Summary

The maximum coefficient of friction during patient transfer from a hospital bed to a hospital stretcher was determined through experimental testing. This coefficient of friction is important due to its direct influence on the forces that translate throughout the patient transfer device during operation. The coefficient of friction was determined using a force gauge, free weights, a hospital stretcher, a hospital bed and length of rope. A total of forty-eight trials were completed at twelve different normal force values. The minimum, maximum, average and standard deviation of the coefficient of friction were found to be 0.59, 0.72, 0.64 and 0.03, respectively.

EGR 403 Medical Device Design

Date Performed: October 11, 2017

Instructor: Dr. John Farris

Introduction

During patient transfer procedures, the patient's draw sheet lies underneath the body and is regularly used as a structural component in the transfer process. Direct care employees grasp the sheet and use it to facilitate patient transfer by applying an upward force to the sheet and pulling or pushing the patient to the desired location. During a transfer process, the draw sheet comes into contact with the fitted bed sheet fixed to the patient's bed. The friction force between the two sheets resists the horizontal movement applied by the direct care employee. During a vertical lifting procedure, the friction coefficient value is not as important due to its lack of influence on the amount of force being moved; however, in the case of the patient auto-slider device, the friction coefficient greatly influences the maximum force being moved and the equilibrium of the system. The patient auto-slider uses a clamp configuration driven by a linear actuator and pulley system to grasp onto the patient's draw sheet and slide them to the bed or stretcher. During operation, the force being pulled by the device is determined by the normal force due to the patient and the friction coefficient between the draw sheet and the fitted bed sheet. This relationship is shown in equation E1.

$$F = \mu N \tag{E1}$$

where F = the force needed to overcome to move the patient in Newtons, μ = the coefficient of friction and N = the normal force due to the patient's mass and acceleration due to gravity, in Newtons.

Due to this relationship, knowing the coefficient of static and kinetic friction is critical in developing mathematical models necessary for verifying proper device functioning. Due to the unique situation in which the human body must overcome a "valley" in the mattress during transfer, the team will find the maximum moving force required, deduce the coefficient of friction

and use that coefficient for further calculation. The team will consider this the maximum friction coefficient throughout the system. Because this value will be larger than the static friction coefficient, calculating the static friction coefficient is not necessary.

Apparatus

Force gauge: WeiHeng WH-C 300

Free weights: 15 lbs., 25 lbs., 45 lbs.

Hospital stretcher

Hospital bed

10-foot length, 0.5 in diameter, static rock-climbing rope

Experimental Procedure

Fitted sheets were installed on both the hospital bed and the stretcher prior to testing. Additionally, a draw sheet was placed on top of the hospital bed's fitted sheet. The draw sheet acted as the vehicle, which pulled the weights across the bed and stretcher. This setup simulated a patient being pulled from the bed to a stretcher by way of the draw sheet. During testing, the friction which impeded motion acted between the fitted sheet surface and draw sheet surface. Once the bed and stretcher were set up, weights were added to the top surface of the draw sheet. The excess amount of draw sheet in front of the weight was tucked in between the weight plates. A small length of rope was used to anchor into the middle of the weight plate and a loop was tied onto the end. The force gauge was then anchored to the loop on the short length of rope. A ten-foot piece of rope was then fastened to the opposite end of the force gauge. A fixed, horizontal support was used to cradle the ten-foot rope to ensure that the height at which the pulling rope was above the ground was consistent during testing. Figure E1 shows an example of a full experimental setup.

Figure E1. Experimental setup

Figure E2 shows a detailed view of force gauge setup. Once the weights and rope were in place, participant one pulled on the rope attached to the force gauge while participant two monitored the force gauge's output. Participant one pulled the sheet full of weights until the weights fully cleared the hospital bed and were fully seated on the hospital stretcher. Once the pull was complete and the highest value output by the force gauge was recorded, participant two re-positioned the weights on the hospital bed and prepared for the next trial.

Figure E2. Force gauge setup

Results and Discussion

From the testing that was conducted, it was determined that all data that was below 100 lbs. would be discarded. The reasoning behind this was that nearly all patients that would pull using the patient mover would be over 100 lbs. So, in order to keep our data consistent with realistic scenarios, our data was reduced from the forty-eight measured values to the thirty-two values that were measured above 100 lbs. Through testing, it was found that the overall average friction value, μ, was found to be 0.64. Figure E3 displays the results in a histogram format. As shown in Figure E3, the friction values gravitated toward the average with a couple of outliers on the higher end. To combat the higher levels of friction that were measured, a mean plus three sigma was calculated. The calculation of the mean plus three sigma determines the highest friction level that would allow for 99.87% of all trials to fall below. This would equate to 1,350 transfers out of 1,000,000 where the friction coefficient would be above the worst-case scenario. Along with the three-sigma shown in Figure E3, the minimum, maximum, standard deviation, and mean are also calculated and shown in Table E1.

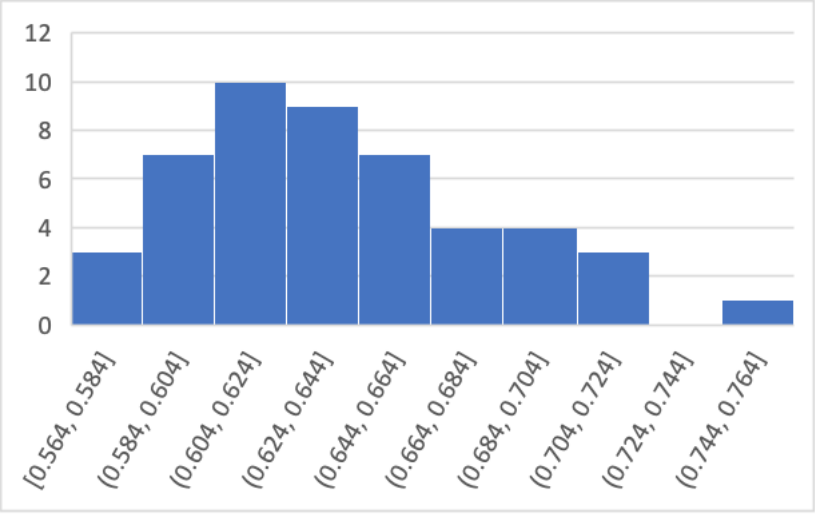


Figure E3. Histogram of friction values from test conducted at SHI

Table E1. Calculated values developed from the friction coefficient measured

Calculated Values Developed from the Friction Values Measured	
Min	0.59
Max	0.72
Standard Deviation	0.03
Average	0.64
Mean + 3 Sigma	0.74

From the calculations, the three-sigma value of friction was found to be 0.74. With the average value of friction being 0.64. As previously stated, 99.87% of transfers would fall at or below the 0.74 coefficient of friction value calculated. Based on this information, the remainder of the patient auto-slider project will use a value of friction of 0.74 for bed to stretcher and stretcher to bed movement.

Conclusions

- The average friction coefficient was found to be 0.62.
- The calculation of the mean plus three sigma determines the highest friction level that would allow for 99.87% of all transfer to fall below. This value was found to be 0.74.
- A standard deviation of 0.03 was calculated from the testing data.
- A coefficient of friction of 0.74 will be used for all current and subsequent equations which depend on the coefficient of friction between the draw sheet and bed sheet.

Appendix 1

Table 1. The complete friction data set.

#	Weight	Max Force	Friction
1	45	34	0.7556
2	45	32	0.7111
3	45	29.3	0.6511
4	45	28.4	0.6311
5	60	43	0.7167
6	60	41.8	0.6967
7	60	38.5	0.6417
8	60	38.3	0.6383
9	75	48	0.6400
10	75	45.4	0.6053
11	75	42.3	0.5640
12	75	44.2	0.5893
13	90	52.4	0.5822
14	90	52.4	0.5822
15	90	57.2	0.6356
16	90	53.1	0.5900
17	105	67	0.6381
18	105	66	0.6286
19	105	64.8	0.6171
20	105	64.3	0.6124
21	120	72	0.6000
22	120	71.8	0.5983
23	120	74.7	0.6225

24	120	74.3	0.6192
25	135	83.6	0.6193
26	135	83	0.6148
27	135	90	0.6667
28	135	82.4	0.6104
29	150	90	0.6000
30	150	89.2	0.5947
31	150	93	0.6200
32	150	100	0.6667
33	155	102.1	0.6587
34	155	101.8	0.6568
35	155	101.8	0.6568
36	155	102	0.6581
37	170	117	0.6882
38	170	101.4	0.5965
39	170	105.9	0.6229
40	170	110.2	0.6482
41	185	129	0.6973
42	185	126	0.6811
43	185	117	0.6324
44	185	120	0.6486
45	200	139.7	0.6985
46	200	143	0.7150
47	200	128.7	0.6435
48	200	132.8	0.6640

Appendix F: Pull Force Verification Form

Project Name: The Design and Development of a Device to Assist in Boosting Patients

Design Verification Number: 1

Date: March 28, 2019 **Author:** Taylor Rieckhoff

Purpose of Analytical Model:

The purpose of this model is to determine the force required to pull the patient up the bed.

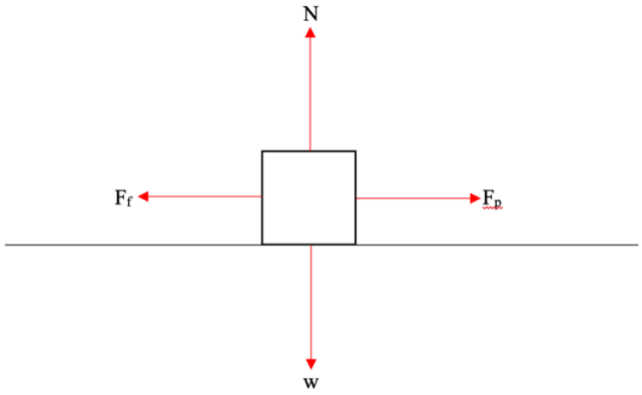


Figure F1. The free body diagram representing the patient on a bed.

Derivation of Analytical Model:

Table F1. The equations derived from the model.

EQUATIONS
Friction Force = μ*w*cos(θ)
Pull Force = μ*w*cos(θ) + w*sin(θ)

Table F2. The calculation for the worst-case scenario.

WORST CASE SCENARIO		
Weight of Patient	500	lbf.
Friction Coefficient	0.74	
Friction Force	156.37	lbf.
Pull Force	156.37	lbf.

Table F3. The calculation for the best-case scenario.

BEST CASE SCENARIO		
Weight of Patient	100	lbf.

Friction Coefficient	0.59	
Friction Force	24.93	lbf.
Pull Force	24.93	lbf.

Assumptions:

1. Patients being boosted weigh between 100-500 lbs.
2. The range of the friction coefficient is 0.59-0.74, derived in Lab Report #1.
3. The static coefficient of friction is used because the kinetic friction coefficient is less.

Conclusions:

The maximum force needed to pull a patient is 156.37 lbf.

Appendix G: Deflection Verification Form

Project Name: The Design and Development of a Device to Assist in Boosting Patients

Design Verification Number: 2

Date: July 31, 2019 **Author:** Taylor Rieckhoff

Purpose of Analytical Model:

The purpose of this model is to determine the deflection of the bracket when the maximum pull force is applied.

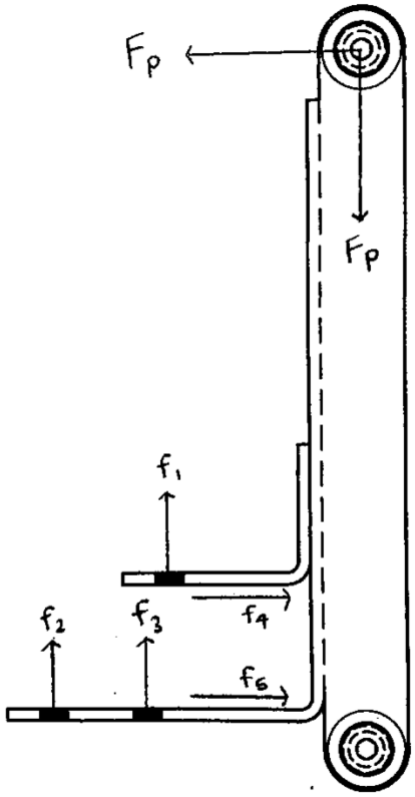


Figure G1. The free body diagram representing the bracket.

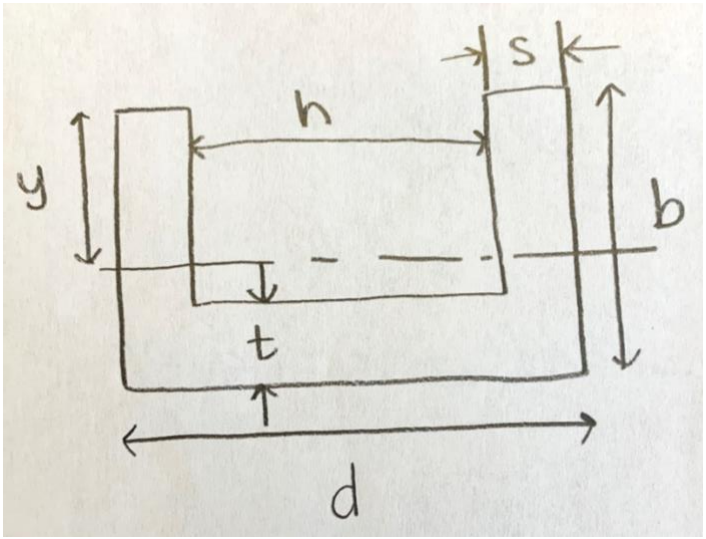


Figure G2. The cross-sectional area of the channel bracket.

Derivation of Analytical Model:

The deflection of the bracket was determined using the following equation

$$\delta = \frac{F_p L^3}{3EI} \qquad \text{(G1)}$$

where F_p = maximum pull force (lbs.), L = length (in.), E = elastic modulus (psi), I = moment of inertia (in^4). The moment of inertia is determined using the following equation

$$I = \frac{2sb^3+ht^3}{3} - A(b-y)^2 \qquad \text{(G2)}$$

where A = area in in^2. The equation to determine y, the distance from the centroid in inches, is determined using the following equation.

$$y = b - \frac{2b^2s+ht^2}{2bd-2h(b-t)} \qquad \text{(G3)}$$

The moment of inertia was calculated to be 0.0204 in^4.

$$y = 0.75 - \frac{2(0.75)^2(0.125) + (2.375)(0.125)^2}{2(0.75)(2.625) - 2(2.375)(0.75-0.125)} = 0.567$$

$$I = \frac{2(0.125)(0.75)^3 + (2.375)(0.125)^3}{3} - (0.484)(0.75-0.567)^2 = 0.0204$$

The maximum deflection was calculated to be 0.045 in. using the maximum pull force determined in Verification Form #1 (Appendix F).

$$\delta = \frac{F_p L^3}{3EI} = \frac{(156.37)(8.00)^3}{3(29\times10^6)(0.0204)} = 0.045$$

Assumptions:

1. The bracket is fixed at the bottom.

2. The maximum pull force of 156.37 lbs. is from Verification Form #1.
3. The elastic modulus of steel is 29,000,000 psi.

Conclusions:

The maximum deflection that will occur to the bracket is 0.045 in. The maximum deflection is located at the top of the bracket.

Appendix H: Stress Verification Form

Project Name: The Design and Development of a Device to Assist in Boosting Patients

Design Verification Number: 3

Date: July 31, 2019 **Author:** Taylor Rieckhoff

Purpose of Analytical Model:

The purpose of this model is to determine the stress in the bracket when the maximum pull force is applied.

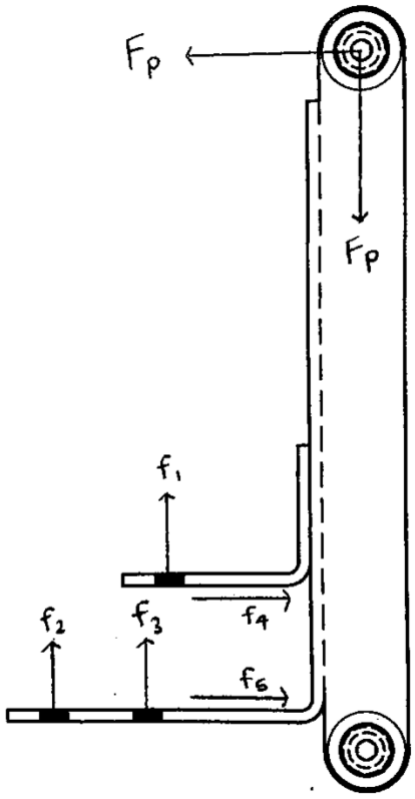


Figure H1. The free body diagram representing the bracket.

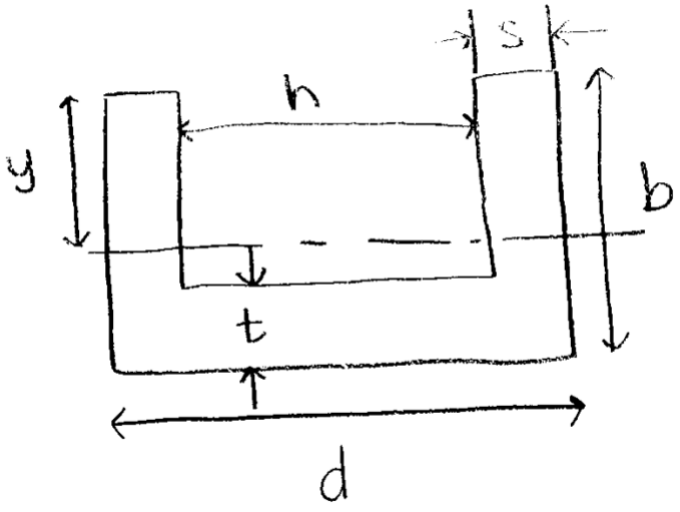


Figure H2. The cross-sectional area of the channel bracket.

Derivation of Analytical Model:

The compressive stress in the bracket was determined using the following equation

$$\sigma_c = \frac{F}{A} \qquad \text{(H1)}$$

where F = maximum pull force (lbs.), A = cross-sectional area (in^2). The cross-sectional area is determined using the following equation

$$A = bd - h(b - t) \qquad \text{(H2)}$$

The area was determined to be 0.484 in^2.

$$A = (0.75)(2.625) - (2.375)(0.75 - 0.125) = 0.484$$

The stress was calculated to be 323.1 psi.

$$\sigma_c = \frac{156.37}{0.484} = 323.1$$

The stress was calculated using the maximum pull force determined in Verification Form #1 (Appendix F).

The bending stress was also determined using the following equation

$$\sigma_b = \frac{My}{I} \qquad (6.3)$$

where M = bending moment (lbs.-in.), y = distance to the neutral axis (in.) and I = moment of inertia (in^4). The bending moment was calculated to be 1250.96 lbs.-in.

$$M = 156.37 \times 8 = 1250.96$$

Using the moment of inertia and y value from the deflection calculation, the bending stress was calculated to be 34769 psi.

$$\sigma_b = \frac{1250.96 \times 0.567}{0.0204} = 34769.3$$

The ultimate strength of steel is 79800 psi. The safety factor was determined to be 2.79.

$$Safety\ Factor = \frac{79800}{34769.3} = 2.30$$

Assumptions:

1. The bracket is fixed at the bottom.
2. The maximum pull force of 156.37 lbs. is from Verification Form #1.
3. The y value is 0.567 in. from Verification Form #2.
4. The moment of inertia is 0.0204 in^4 from Verification Form #2.
5. A-36 steel was used.
6. The bracket thickness is 0.125 in.

Conclusions:

The maximum stress that will occur to the bracket is 323.1 psi. The bending stress is 34769 psi. The location of the bending stress is located at the bottom of the bracket (0 in.) where it is fixed to the bed. The safety factor is 2.30.

Appendix I: Final Testing Lab Report

The Determination of the Maximum Weight the Patient Booster can Pull

By

Taylor Rieckhoff

Executive Summary

A volunteer, four medical simulation dummies and a backpack were used to test the final prototype's pulling capabilities. The volunteer weighed 145 lbs., each dummy weighed 63 lbs. and the backpack weighed 20 lbs. The maximum weight pulled by the device was 397 lbs. The distance pulled with 397 lbs. was 4.0 inches. The distance pulled with 271 lbs. was 9.0 inches. The distance

pulled with 63 lbs. was 11.0 inches. Sources of variation in testing were the starting point of the weight pulled and how tight the straps were initially.

Date Performed: July 15, 2019

Introduction

The objective of the experiment is to determine the maximum weight the device can pull. The capacity of a hospital bed is rated as 500 lbs. This means that a standard hospital can support patients weighing 0 – 500 lbs. Because the hospital bed is rated to support a 500 lb. patient, the ideal weight for the device to be able to pull is 500 lbs. At the minimum, the device should be able to pull 350 lbs., which is the weight of a patient when bariatric procedures may take place out of precaution. Bariatric procedures may include using assistive tools or requiring more than four people for patient handling (Muir & Archer-Heese, 2009).

Apparatus

Volunteer – 145 lbs.

4 Medical Simulation Dummies – 63 lbs. each

Backpack – 20 lbs.

Stryker Bed: Model No. 3005S3

Straps

Brackets

Clamps

Experimental Procedure

The device was installed on the hospital bed. The clamps were clamped on to the draw sheet of the hospital bed. The bed was lowered down as far as possible. To start, the prototype was tested with one dummy. The dummy was placed on top of the draw sheet, and the straps were adjusted to be as tight as possible without pulling the draw sheet. The bed was raised vertically to the highest point. The weight and distance pulled was recorded. The procedure was then repeated with a dummy and a backpack. The next trial included the volunteer and two dummies. The final trial included the volunteer and four dummies. The weight, distance pulled and the time for the weight to move was recorded after each trial.

Results and Discussion

Table H1 summarizes the results of the experiment.

Table H1. Results of the experiment.

Weight Pulled (lbs.)	Distance Pulled (in.)	Time to Start Moving (s.)
63.0	11.0	8.0
271.0	10.0	8.0
397.0	4.0	14.0
417.0	0.0	-

At lower weights the distance pulled was higher than when tested with heavier weight. When pulling 63.0 and 271.0 lbs., the weight was pulled in one motion. When pulling 397.0 lbs., the

weight was not pulled in one motion but rather in two increments. The stuttering was an indication that the device was near its maximum weight limit. The next available weight to add was a 20 lb. backpack. When the backpack was added, the straps tightened moving the clamps while also stretching the sheet; however, the weight did not move.

A source of variation in the experiment was the starting point of the weight before raising the bed. When more weight was loaded on the bed, the size of the load made it difficult to keep the starting point exact between trials. Another source of variation was how tight the straps were at the start of each trial. After each trial, the straps had to be readjusted to move the draw sheet and weight back down toward the foot of the bed. Each trial had a slightly different strap tightness to start which would influence the height at which the straps overcame the static friction and started pulling the weight. If the straps started pulling early on in the rise of the bed, then there would be a greater potential distance pulled. If the straps had more slack at the start, then the potential maximum distance pulled would be less.

The time to start moving was 8.0 seconds for the trials with 63.0 and 271.0 lbs. This is an indicator that the quality of the performance of the device was similar for both trials. Because the trial with 397.0 lbs. resulted in a longer time to start moving the weight, that indicates the quality of performance was lower for that trial, in addition to the stuttering mentioned prior.

Conclusions

- The maximum distance pulled was 397.0 lbs.
- The distance pulled with 397.0 lbs. was 4.0 inches.
- The starting point of the weight and the tightness of the straps influences the performance of the device.
- As the weight increased, the distance pulled decreased.

References

Muir, M., & Archer-Heese, G. (2009). Essentials of a Bariatric Patient Handling Program. *The Online Journal of Issues in Nursing*.

Appendix J: Bill of Materials

Table J1. The Bill of Materials.

Component		**Prototype Cost**		**Production Run Estimate**
1" Wide Bracket				
	Material and Laser Cutting	Part A	$ 32.00	
		Part B	$ 24.00	
	Fabrication / Welding		$ 30.00	
	Bolts and Misc. Hardware		$ 11.00	
	Total		$ 97.00	$ 55.00
2" Wide Bracket				
	Material and Laser Cutting	Part A	$ 32.00	

		Part B	$ 24.00	
	Fabrication / Welding		$ 30.00	
	Bolts and Misc. Hardware		$ 16.00	
	Total		$ 102.00	$ 55.00
Machined Clamp				
	Material and Machining	Top	$ 115.00	
		Bottom	$ 115.00	
		Slide Nut	$ 36.00	
		Rod	$ 22.00	
		Eyelet	$ 12.00	
	Fabrication / Rubber Coating		$ 15.00	
	Total		$ 315.00	$ 115.00
Vise Grip Clamp				
	Material		$ 20.00	
	Fabrication / Welding		$ 50.00	
	Misc. Hardware		$ 11.00	
	Total		$ 81.00	$ 60.00
Strap			$ 18.78	
	Total Cost		**$ 613.78**	