# Support System for Fall Protection During Gait Studies

# Background Research

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# 1 BACKGROUND

## 1.1 Introduction

Do you or someone you know suffer from neuromuscular disorders such as cerebral, palsy, deficits due to stroke, or spinal cord injuries? Many therapy cases today state that patients endure the fear of falling when undergoing therapy where studies of their gait are performed. Assistive devices to help participants walk have already been commercialized. However, the cost is a large factor for many facilities that study these cases due to the devices being intricate and expensive. The overall goal of this project is to design and engineer a device that can assist these types of people at a fraction of the cost of some that are already available. It is imperative that this device still meets the same needs and requirements of the researchers and patients themselves. Our team's sponsor, Dr. Zach Lerner, works within NAU's Human Performance Lab where he researches and studies how people with neuromuscular disorders walk. He is in need of a device to help him practice his studies of their gait within his lab. Our team has been contracted to produce a system that can attach to a patient while they undergo Dr. Lerner's studies without having a fear of falling with their disorder. The system must allow the patient to walk under their own power. However, it must also protect them from falling if they happen to do so. Issues with current systems are that they are expensive, interfere with motion tracking cameras, take up too much space, and can be uncomfortable to the patient. Our objective is to create a system that is user-friendly, conscientious of space, and affordable.

## 1.2 Project Description

Following is the original project description provided by the sponsor.

> "The Biomechatronics Lab uses robotic exoskeletons to improve walking biomechanics in individuals with neuromuscular disorders. Study participants practice walking with the assistive devices in NAU's Human Performance Lab. Because many of the participants have neuromuscular deficits due to stroke, spinal cord injury, or cerebral palsy, they are predisposed to falling. The goal of this project is to design a fall protection system to use during overground and treadmill gait studies. Commercial systems may be difficult to integrate into the existing lab space and are expensive."

## 1.3 Original System

This project consists of redesigning existing commercial designs to make it more cost effective and accommodating. In the present market, there are a variety of devices that can complete the task of holding a patient up if they were to fall during a gait study. These devices can either be mobile or use a track system attached to the ceiling. For a mobile device, the device may be able to be dismantled, allowing it to be transferred from location to location. The disadvantage of this type of device is it may not be able to withstand the amount of force a falling patient may emit. Another type of mobile device is one that is small enough to move around a room but not easily disassembled. An example of this sort of device would be the Biodex NxStep Unweighing System. The NxStep allows for movement around a room, variety of patient heights, fitment around a treadmill, and collapses to 32" wide [1]. This device is not easily disassembled to move to a different location but can be moved from room to room within the same building.

If the falling protection device is not mobile, it is frequently mounted to the ceiling with a track system. The systems mounted to the ceiling usually have a higher weight rating allowing them to care for a wider range of patients. Also, as demonstrated by products from SoloStep, they can come in a variety of shapes such as a straight line, j-shaped, u-shaped, and an oval [2].

Each different shape has their advantages and disadvantages based on their application. For example, a physical therapy room may be small in size but the therapist's need to have their patients walk for a longer period. In this case, the best ceiling mounted track shape would be the oval which allows for the patient to continuously walk without stopping.

These devices mentioned above have been commercialized and are too expensive to be used in smaller gait study or therapy locations. These locations are in need of a device to keep their patients from falling while they are moving around the room as well as walking on a treadmill at a lower price.

### 1.3.1 Original System Structure

Typical gait study devices come in the form of two styles. The first style localizes itself around a track-mounted system, which is attached to a load-bearing beam above the area where a participant will walk and have their gait tracked. Aretech is a company who produces a device called the Zero G, which is centralized around the track system. The Zero-G incorporates a robotic trolley that automatically tracks patient’s movements up to 6 mph [3]. Parts of the original system include a metal track, trolley, and suspension tether. Additional parts include the patient’s harness, interactive technologies which track gait, and user-interfaces.

The second type of system is a mobile frame, which moves along with the patient as they walk. These types of systems are fairly bulky and are formed with metals capable of supporting the patient’s weight. The frames are mounted to a set of wheels that allow the system to move with the patient. An overhead beam built into the frame is usually the place where the patient can be attached via a harness to ensure that they are protected if they happen to fall.

Most of the original systems materials include lightweight metals and durable plastics. These devices are usually housed within therapeutic facilities and research laboratories.

### 1.3.2 Original System Operation

Another existing fall prevention support system is the Bioness Vector Support. The basic functions of design can be seen in the Function Model in Figure 1. This design has the capability to support up to 500 lbs. of weight and can be customized to support a specified amount of weight to relieve from the patient during therapy. The design of the automated motor on the overhead track is unique from others because of the exposed coiled support line on a wheel drum. The onboard integrated computer system coupled with the hydraulic pump offer precise outputs (such as weight relief) and data collection. The support system also tracks the distance, weight, and number of falls for each therapy session. From the tracking that occurs 1000 times per second, the computer analyzes the data trends and adjust the cord length and the support of the weight to accustom to the walking patterns of the patient. The Bioness Vector support also has wireless remote to send commands to the support unit [4].

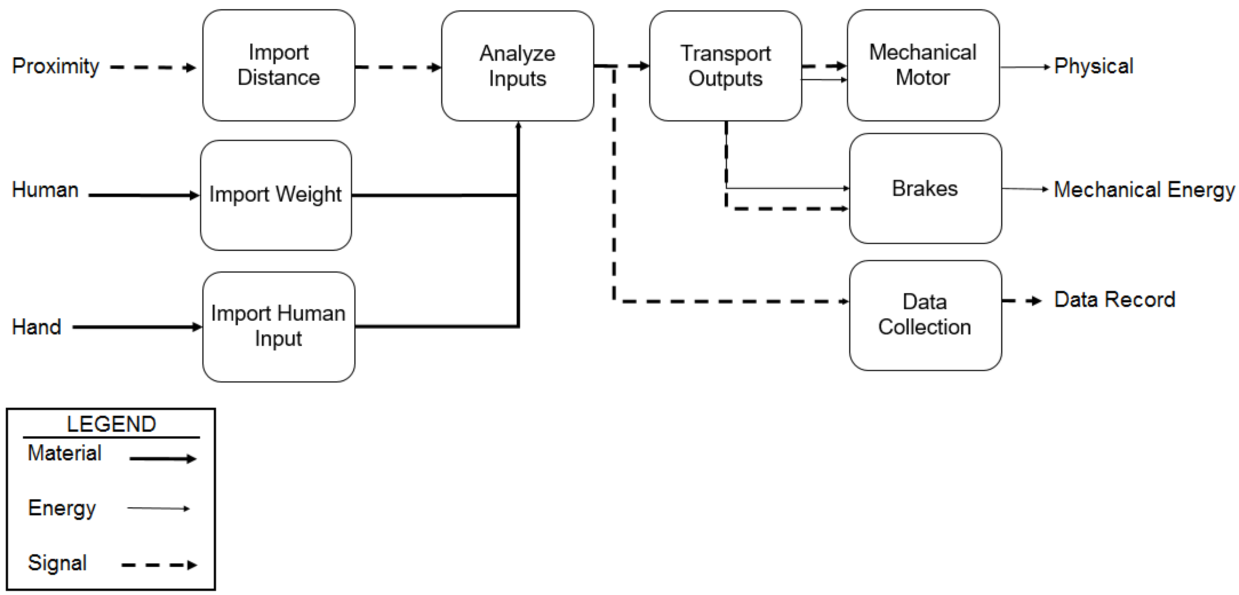


*Figure 1: Functional Model*

### 1.3.3 Original System Performance

Currently, the support system performance is functional, safe, and interactive. For all variations of the original system, catching people before they fall to the ground is the main concern considering performance. To accomplish this first major performance concern, static and dynamic force calculations at the tether connected to the track connected to the user must occur. Data collection and customer requirements help compute these calculations for weight, volume, speed, accuracy, power, and efficiency of the system. The original system can hold between a maximum of between 400-500 pounds of static body weight and 10-200 pounds of dynamic body weight [4]. In addition, the system is able to perform at various speeds of user locomotion, typically near a maximum speed of 6 mph. In addition to speed performance, the system is also capable of breaking when it exceeds the maximum speed, which contributes to a high safety performance for intensive rehabilitation.

The original system also includes interactive components to track the movements of the user rapidly (at 2500 times per second) and transfer this data to different software that drives the actuator positioned on a track and displays images of highlighted movement [5]. Phones or tablets may be linked to the patient management software to track patient growth and create/manage care plans. Another interface can link with a mobile device as a remote control for adjusting the system to meet the user needs. The actuator follows the movement of the user while maintaining enough slack in the tether for more comfortable mobility. Additionally, the actuator will simulate freedom of the device for mental awareness strengthening. The slack allows the user to feel free of the device, challenging them, yet instilling confidence at the same time. Tracking the data and displaying a computer image of movement highlights the areas for improvement and allows for more immediate adjustments that the therapist may direct to the user. Overall, the performance of the support system is functional, safe, and interactive.

### 1.3.4 Original System Deficiencies

The main concern with gait study systems currently available is their cost and within our teams instance our customer's need is a more affordable cost. Our client would love to have one of the commercial devices available, but with some costing over $100,000, they are not feasible for him. Due to this need, our team is focused on designing a system that functions at the same level as one of the expensive devices however at a much lower overall sum. Along with cost, another need for our client that is not met by the original system is interference with motion detection cameras. Some designs utilize a frame to suspend its patients, which can be in the way of where the cameras need to be focused on the patient to gather accurate data. Due to this problem, our team has decided that the best option for our client is a ceiling mounted track system which only has a tether exposed at the level of the cameras. By only having a tether that suspends the patients to prevent falls, the cameras will have better angles to track the patient's gait and overall provide our client with better data for his research.

# 2 REQUIREMENTS

The following sections will outline the customer requirements our team has set, the rankings are given to us by our client, and the House of Quality used to determine which customer and engineering requirements to focus on.

## *2.1 Customer Requirements (CRs)*

The customer requirements listed below in Table 1, is the requirements expectations of our team by our client and users from the re-design of a support system for gait studies.

*Table 1: Customer Requirements*

| Customer Requirement # | Customer Requirements |
|---|---|
| 1 | Cost to Build |
| 2 | Safety |
| 3 | Non-Obstructive/Low Profile |
| 4 | Non-Reflective |
| 5 | Treadmill Compatible |
| 6 | Must Move 5 meters |
| 7 | Unweighted System (Zero Tension) |
| 8 | Comfortability |
| 9 | Easy to Operate |
| 10 | Minimal Maintenance |
| 11 | Durability |
| 12 | Reliability |
| 13 | Adjustability |

**1. Cost to Build**

The total cost of the project must abide by the $2,500 budget set by the client. The design needs to incorporate materials that will economically suit the budget.

**2. Safety**

Must safely support a patient's body weight and movements while in use.

**3. Low Profile**

The system must not restrict the line of sight of the Vicon infrared motion detection cameras.

**4. Non-Reflective**

Color/texture of system cannot interfere with infrared motion detection cameras.

**5. Treadmill Compatible**

The support system allows the patient to use support when walking on the treadmill.

**6. Must Move 5 meters**

The ability for the patient to move a minimum of 5m in forward or rearward direction.

**7. Unweighted System (Zero Tension)**

No partial weight bearing system; tether must not be under tension with patient attached.

**8. Comfortability**

The patient must not feel discomfort while operating the system to avoid interfering with the gait analysis.

**9. Easy to Operate**

The system must be easy to operate by both the patient and therapist.

**10. Minimal Maintenance**

The design needs to have zero to minimal maintenance required over long durations of operation.

**11. Durability**

Longevity over periods of operation and repeated fall prevention is required.

**12. Reliability**

The system must not fail when being used and must catch the patient from falling.

**13. Adjustability**

The system must be able to be used for small children to elderly adults ranging in heights and weights.

## *2.2 House of Quality (HoQ)*

The House of Quality in Appendix A: Figure 1, is an engineering tool used to define the relationship between customer requirements and the engineering requirements as well as other products on the market. Currently, our HoQ has the customer requirements and the weight in a number between 1-5 given by the client. At this time, the ranking and approval of the customer requirements are in progress. This list of customer requirements displayed in the HoQ is the un-approved list of customer requirements.

# 3 EXISTING DESIGNS

Our team has conducted a variety of research to successfully re-engineer a support system for fall protection during gait studies. This type of system already exists in the marketplace, however, are very expensive and not practical for personal uses.

## *3.1 Design Research*

Our team conducted research on several overall systems and subsystems found in a fall prevention support system. The four overall systems include Bioness Vector Support, SafeGait 360, Aretech Zero-G Gait and Balance Training System, and BioDex NxStep Unweighing System. These four devices range in how they operate, prevent a fall, and study gait. Our team focused mainly on ceiling track mounted systems for our subsystems. The four subsystems include a user interface, track system, trolley, and a tether to connect to the patient. The user interface allows for easy operation and collection of gait analysis by the trainer. The trolley is used to catch the patient from falling but move with the patient when they are walking. The trolley will be mounted to the track system which is then mounted to the ceiling to ensure a sturdy and reliable device. The tether is used to connect the patient to the trolley to prevent a fall.

Our team did all of our research by utilizing the search engines such as Google. This allowed us to view a number of devices already in the market in a quick amount of time. The manufacturer's websites do not discuss the design portion of the device but rather the applications of their systems. The application details found on their websites helped us develop an idea of how we may want to alter their designs to suit our project needs better. For example, a portable system with many different members may block the view of the infrared motion detected cameras. To solve this, we may re-design it only to have one member connecting to the patient where the cameras are not located to not interfere with the gait studies. The following sections will discuss the four overall systems and four subsystems.

## *3.2 System Level*

### 3.2.1 Existing Design #1: Bioness Vector Support

The Bioness Vector Support (BVS) system is one of the finer supports that a physical therapy office might purchase. The BVS meets several of the Customer Requirements (CR) and just as well lacks the ability to meet other requirements. Beginning with the strengths of the BVS system that meet the CR's is the weight capacity to hold up to 500 lbs [4]. This model specification supersedes the maximum amount of weight required and could yield information of how our design can incorporate the same engineering designs to hold up to 300 lbs. Another detail of the BVS is the capability that it can be erected to run on an overhead track of five meters or more including over treadmills. The BVS can also adjust the amount of weight to withhold from the patient all with a touch of a button from a smartphone, tablet, and or computer [4]. This specification is useful to our project because of the CR to have zero tension in the tether attached to the harness. The tension in the line would interfere with the patient's ability to perform the therapy exercise correctly. Indirect link to tension is the comfortability of the design on the patient. The BVS system uses the adjustability to accommodate to the patient's unique body by allowing enough slack in the tether, not to be pulling on the harness, while also maintaining a slight tension to prevent minimal free fall and agile response to a falling patient.

While the Bioness Vector Support has many attributes that meet several of the customer requirements, there is also some design of the BSV that don't meet some of the CR's. The system cost of the BVS is beyond the $2,500 budget. While the BVS system is of high quality and has minimal maintenance, the support would require maintenance a special technician will be sent to perform the work necessary to repair or maintain the device. The repair could add additional cost to the overall ownership cost for the client. In our design, it will be important to ensure the support system will have less than minimal maintenance, if none at all, and could be maintained by any mechanically experienced personnel rather than a special technician.


*Figure 2: Bioness Vector Support [4]*

### 3.2.2 Existing Design #2: SafeGait 360

The SafeGait 360 is an interactive support system currently on the market that specializes in balance and mobility training. This system is composed of six major components- rail, actuator, harness, closed wireless system, patient management software, and hardware. The rail may be fixed from the ceiling and customized as a straight of full loop configuration, "U" or "J" shaped. This rail design accommodates for the facility space and requirements - such as treadmill accessibility. An actuator attached to the railing is "a stealth, state of the art support and tracking device that moves with the patient" [5]. Acceleration of the user matches the motion of the actuator, which helps the user keep balance and have the illusion of walking freely with confidence. The harness design was generated from therapists to maximize the patient's comfort by introducing counter uplifting forces with leg cuffs and straps around the torso. Next, the support system interacts within a closed wireless system that provides security, privacy, and connectivity. The closed wireless system ensures no other wireless signals will interfere with the rehabilitation device, minimizing the source of error. Another system component is the patient management software that uses a smart and user-friendly interface to manage patient statistical data and customize a care plan. Data gathered from the therapy sessions can detail summary of progress and export this progress in a chart format into the patient health records. Lastly, the hardware connects with this software with a mobile device, such as a phone or tablet for flexible control options.

Since safety is one of the primary goals for this system, four major device components are implemented - dynamic fall prevention (DFP), decent limits, body weight support, and a horizontal lock. The dynamic fall prevention is a software that can distinguish between a user's intentional movement downwards and when they are experiencing a fall. This software is able to adjust sensitivity levels of the patient at varying independence stages - low, medium, and high. The backup fall protection feature is a decent limiter that sets a maximum downward travel distance based on the patient's position and height. Having a backup fall preventing device is something to consider for the design of our support system to ensure safety. Another safety feature is the body weight support, that can adjust to unload the patient up to 50% of their weight at a 175 lbs. maximum. The final major safety feature is the horizontal lock that allows for vertical travel as desired for a steady place to anchor onto a treadmill or for push/pull training. In all, this system is an exemplary device that facilitates valuable patient/ therapist interaction in a modern, safe, and efficient environment.


*Figure 3: Safe Gait Support System [5]*

### 3.2.3 Existing Design #3: Aretech Zero-G Gait & Balance Training System

There are a handful of current commercial gait training systems on the market today. One of these systems is Aretech's Zero-G (Figure 4,5), which is a ceiling mounted track system that suspends the patient from an overhead robotic trolley. The technology integrated into this design is advanced and has an interactive data analysis system, which tracks a patient's gait and is displayed on an interface that both the patient and therapist can view. The Zero-G offers a wide range of patient diagnosis from spinal cord injury to cerebral palsy and has a weight range of 20-400lbs [3]. The Zero-G allows a variety of functionality allowing a patient to practice walking, balance-activities, postural tasks, sit-to-stand exercises, stair walking, and getting up off of the floor. The robotic trolley allows tracking of a patient at up to 6 mph and is offered in track sizes of up to 85 feet [3]. Tracks can be configured in straight, J-curved, U-curved, or customized options to permit installation in most facilities [3].

*Figure 4: Zero-G V.2 [3]*

*Figure 5: Zero-G V.2 [3]*

The Zero-G is a well-renowned system that meets many of the requirements our team believes is going to be important to implement into our own design. The overhead track system is of particular interest to our team, as our client wants to conserve as much space as possible within his research laboratory. A track configuration allows for the system to keep up and out of the way of the floor space when not in use. Another component that the Zero-G includes which we are also considering incorporating in our design is a frictionless trolley, which lets the patient move freely wherever the track allows them too. Wide range patient compatibility is another important need of our client that the Zero-G utilizes in its design. The ability to offer a size range from child to adult is essential as research can be conducted on virtually any patient. Our client also requires that our design will have the ability to be used on a treadmill. Having an overhead suspension system like the Zero-G is vital because the tether in which the patient is strapped to can be retracted to allow for obstacles like stairs or a treadmill to be inserted under them. After conducting a thorough investigation into Aretech's Zero-G, there are a multitude of ideas our team may utilize in our own design.

### 3.2.4 Existing Design #4: Biodex NxStep Unweighing System

Another design our team is interested in is the Biodex NxStep Unweighing System which utilizes a mobile system to prevent patients from falling. This device can be used for patients who have had a spinal cord injury, stroke or traumatic brain injury, Parkinson's disease, older adults, amputation of a lower extremity, orthopedic patients, and much more [1]. This system allows for the user or therapist to select the amount of weight to take away from the patient and to raise or lower the height bar depending and the height of the patient. The weight load variation can be very useful because if someone has a very hard time holding their weight, this system can take up to 400 pounds to help the person start to walk with less weight on their legs [1]. The overhead bar is connected to the harness to allow for distribution of forces the patient may feel if they were to fall. The overhead bar is then connected to a tether at a single point. This system can be used with a treadmill to allow for gait studies to occur without having to have the patient be constantly moving around the room. In this case, the patient can be in one place but still have movement. As an added bonus, the system does come with two different therapist seats, one on either side of the system to allow for a comfortable working environment for the therapist while the patient is on the treadmill [1].

This system is a very important system to us for several reasons. First, the system can fit around a treadmill which is one constraint given to us by our client. Secondly, the system does not fill a lot of space within the room to hold the patient up in the event of a fall. A concern from our client was that if we were to build a mobile system, then it would interfere with the motion tracking cameras that are set up. If we were to make a design similar to the NxStep System, then there would be little to no interference with the motion tracking cameras. Lastly, the system can hold a patient weighing up to 400 pounds. The weight limit we have been given is around 250-300 pounds to withstand. It would be in our best interests to break down this system and see exactly how it can withstand 400 pounds safely and how we can utilize that within our designs to hold 250-300 pounds.

## *3.3 Subsystem Level*

At a subsystem level, the general existing designs can be decomposed into User Interface, Brake and Motor, Track, and Tether. Each of the subsystems is critical components that existing designs on the market apply different engineering designs. In this section is the result of research from the existing subsystems that could influence the future concept generation process. Along with the research is an analysis of the existing subsystems fulfillment of the customer requirements.

### 3.3.1 Subsystem #1: User Interface

The user interface is one of the more critical components because it is the only interface that the client (Physical Therapist) will have contact with the support device. The customer requirements that apply to this subsystem are the adjustability, reliability, durability, and cost. Each of these requirements will help to ensure that the research of the human interfaces will contribute to future engineering concepts and design.

#### *3.3.1.1 Existing Design #1: Flex EX Remote*

The Flex EX is a remote seen in Figure 6 that serves the purpose of the controlling overhead cranes that handle various materials. The remote is wirelessly connected to the support system and can control the operation of the crane. The remote meets the customer requirement of adjustability by offering various commands at a push of a button. The Flex EX remote is simple in design and durable. The remote can be programmed to perform over 200 functions if necessary [6]. This option to program could be promising to involve in our design because it could control multiple motors from one remote if the design uses more than one.


*Figure 6: Flex EX Remote [6]*

#### *3.3.1.2 Existing Design #2: Smartphone & Computer Control*

The more widely used subsystems associated with nearly any support system on the market is a software application offering remote control from a smartphone, tablet, and computer. This type of interface is more conventional and intuitive because of the practical ease of operation. As seen in Figure 7, the software application offers adjustability from the position of the overhead support to the amount of tension in the line supplied. In addition to the controls, the software simultaneously records data from the therapy session and offers data tables and charts that can further aid the physical therapist to make adjustments to patients therapy. Though our design may not incorporate an extensive software application as seen with many support systems on the market, our design may build a use a simple application to control the overhead unit from any smartphone or computer. The big challenge to building a simple app is making it compatible to both operating systems of Android and Apple. The reliability, durability, and cost are all correlated to the individual specification of the client's current computer and smartphone.


*Figure 7: Smartphone & Computer [4]*

#### 3.3.1.3 Existing Design #3: Self-Retracting Life Line

The last medium of human interface is minimal to no contact at all. The Self Retracting Lifeline in Figure 8, comprises of gears and springs to self-retract and just as well stop a fall when one is occurring [7]. The self-retracting system is generally used in the industrial field where there is a potential risk of falling. This system offers the freedom to move around with the security of a fall being prevented. The client would only spend time hooking the lifeline to the harness. The lifeline can typically be adjusting by weight so that the tension on the line remains insignificant. This adjustment would be down manually and would require the client to use a step ladder to reach the main hub to make the weight adjustment. Self-Retracting Lifeline units run approximately $500. The price of the lifeline is 20% of the budget and would meet the client requirement of the set budget of $2,500. The product is also extremely durable because of the tough environments of the industrial field the lifeline is designed to endure. The high level of durability may not be necessary for the Lerner Support design, but the internal system to prevent falls could produce inspiring concepts.


*Figure 8: Self-Retracting Life Line [7]*

### 3.3.2 Subsystem #2: Trolley

Using a track system requires a trolley to attach on the track, move smoothly along with a user's motion, and hold the weight of a person up to 500 pounds. There are three different trolley options to meet the needs of our system - geared, motorized, and push trolleys.

#### 3.3.2.1 Existing Design #1: Gear Trolley

This type of trolley helps provide positive load positioning along the total beam that will fit most I-, S-, and W-beams. The geared trolley in Figure 9, is designed with a baked enamel paint for protection and precision ball bearing wheels. A benefit to this all-steel construction with hardened axles and lubricated wheel design is its durability and wear resistance. The extra durability will help keep the system safe. Additionally, the geared trolley has an easy installation to hoist. Another benefit of this design is the precision provided by the hand chain gear system. This precision would help guide the user with confidence for the purpose of our system. The hand gear system is also good because it does not require power equipment to do the work over straight or curved tracks. In all this is a reliable and efficient device to use for the trolley component [8].

*Figure 9: Geared Trolley [8]*

#### *3.3.2.2 Existing Design #2: Motorized Trolley*

The motorized trolley is described as durable, reliable, and powerful.  This design has larger wheels than similar models, to maintain and withstand severe use at or near rated capacities. Additionally, this trolley is easily adjustable for a range of different beam widths big or small. The trolley is powered by TENV motor that is designed to ventilate but also prevents liquids and solids from entering the machine. This type of motor is also compatible with a remote control to hoist and move loads with a push of a button. Lastly, the motorized trolley can have add-on features that will increase brake and gearbox life as well as reduce power consumption.  This will be a good option for our design because of the adjustability and durability factors [9].

*Figure 10: Motorized Trolley [9]*

#### *3.3.2.3 Existing Design #3: Push Trolley*

The push trolley in Figure 11, is the last option for the system, capable of 1/4 to 3-ton capacities. Included with the device are lifetime lubricated precision ball bearings that ensure minimal manual effort and limited maintenance. A specific push trolley from the company Chester Hoist is equipped with "eight duo-sealed Timken tapered roller bearings that absorb the radial and thrust loads exerted in the heavier sizes" [10]. The stability and rigidity for the trolley come from the shaped heavy rolled steel side plates that extend passed the wheels to behave as bumpers. The two halves of the trolley are connected by steel equalizing pins that provide smooth operation and load equalization. The wheels of the trolley are long and made of cast iron and have machined threads for extra smoothness for rolling motion. The axles in the side frame are made of steel for rigid support. Also, steel trolley blocks reinforce the side plates as well as equalize the pin. A push trolley design would be the most beneficial to our system because it is free from a power source, has low friction, and a high weight capacity.

*Figure 11: Push Trolley [10]*

### 3.3.3 Subsystem #3: Track Configuration

In this subsystem, the track is one of the parts that has numberless designs and options. From rails to beams, the selection of the right track is critical to meeting requirements of cost, durability, safety, reliability, and minimal maintenance. The research of existing designs shows tracks that are found in industrial applications to support systems.

#### *3.3.3.1 Existing Design #1: Rollon Linear Rail Systems*

Rollon Linear Evolution's compact rail systems are track configurations available in T, K, and U profiles made from 100Cr6 hardened steel [11]. These tracks, seen in Figures 12-13, are designed for applications in aerospace, medical, railways, automation, industrial machinery, and logistics. The tracks consist of induction hardened raceways and high precision radial ball bearing sliders that are affordable and easy to install on all types of surfaces including non-machined surfaces. They have two slider types: N-series aluminum die-cast bodies and C-series with steel bodies. The sliders are resistant to dirt and other forms of debris and include lubricated-for-life bearings. Technical features include: max operating speed of 9 m/s, max acceleration of 20 $m/s^2$, and a max radial load capacity of 15,000 N (337 lbs.) [11]. These track systems also allow for adjustable preload.

Figure 12: Rollon Track [11]

Figure 13: Rollon Slider [11]

#### 3.3.3.2 Existing Design #2: I – Beam

Another form of track structure that may be suitable for our design is an I-beam. I-beams are available in a wide range of sizes and materials such as aluminum and steel. An I-beam can be a simple solution for a track to mount a trolley on as they are capable of supporting heavy loads and can be machined for a close to the frictionless surface for wheels or roller bearings to move along. Although there is a tendency for I-beams to be expensive, they are capable of meeting our client's need of being able to support a max patient weight of 300lbs.

Figure 14: I - Beam [12]

#### 3.3.3.3 Existing Design #3: Box Sliding Rail

Real Sliding Hardware is a company that produces industrial grade sliding hardware. Their typical system consists of a rail trolley that moves inside of a box rail track. Real Sliding Hardware, found in Figure 15, has designed their box rails to be used in exterior or interior applications and are formed out of galvanized or stainless steel that can be powder-coated to customer specifications. If a personalized order is requested, Real Sliding Hardware can be manufactured to custom track lengths and applications. Kit sizes are available in a range of 6-50 feet with their strongest box rail being capable of supporting 800 lb [13].

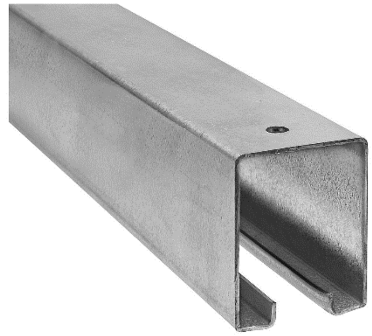

*Figure 15: Box Rail [14]*

A box rail track could function as a useful design to base our trolley mechanism off of within our system. With steel as a structural base for supporting the patient, the integrity of a box rail track will meet our client's requirements of safe and reliable. The ability for application customization may also be helpful in fulfilling our client's requirement of a low-profile and non-reflective track system.

### 3.3.4 Subsystem #4: Tether Material

Support systems, such as Bioness, or Areteck, use a different material to secure the patient to the support system overhead. The selection of material is important because of the repeated stress that will be put on the tether during normal use. Existing tether uses to support patient's o from synthetic polymers to metallic cables. The tether is also important part of meeting the safety, reliability, and durability requirements

#### *3.3.4.1 Existing Design #1: Double Braided Nylon Rope*

There are several materials one can use to keep a person from falling. One of these materials is a double braided nylon rope that can come in a variety of sizes to withstand a range of tensile strengths. For example, a size of ¼ inch thick double braided nylon rope has a tensile strength of 2,200 pounds on average [15]. For our project, we will first need to calculate the max amount of force that will be exerted by the patient onto the tether to know what thickness our tether will need to be. The double braided nylon rope distributed by Knot and Rope Supply come in thickness from ¼ inch to 1 inch where the one inch has a tensile strength of 26,000 pounds on average [15].

#### *3.3.4.2 Existing Design #2: 7x19 Grade 304 Vinyl Coated Stainless Steel Cable*

Another option for a material being used as a tether would be a stainless-steel cable coated with vinyl. This type of cable will be able to support on average from 350-1800 pounds depending on the thickness of the cable [16]. The vinyl coated stainless steel cable will provide less friction on the trolley making it easier for the patient to walk with the tether attached. If the tether cable were to have a high frictional force going against the patient, the patient will have a harder time walking and will affect the gait analysis. The stainless-steel cable in Figure 16, also has high flexibility, corrosion resistance, and abrasion resistance. The flexibility will become very useful in our design as we do not want a tether that is extremely tight on the patient because if the patient were to fall, the force from the cable onto the patient would be enormous, possibly causing injury. The image below is an example of 5/16 inch, 7x19 Grade 304 Vinyl Coated Stainless Steel Cable.

*Figure 16: Vinyl Coated Stainless Steel Cable [16]*

#### *3.3.4.3 Existing Design #2: Antenna Support Rope*

Antenna support rope in Figure 17, is manufactured by Synthetic Textile Industries is a cheaper, yet very strong material a tether. The diameter of the rope is 5/16 inches with a breaking strength of approximately 1,790 pounds [17]. Antenna support rope is made from double braided polyester rope to ensure the reliability and durability of the system. This rope is distributed from DX Engineering and costs about $25 for 100 feet which is more than enough for our application [17]. I believe, after calculating the force from the patient, this rope will provide sufficient strength to catch the patient from falling without an abrupt pull on the patient.

*Figure 17: Antenna Rope [17]*

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# APPENDIX A: House of Quality

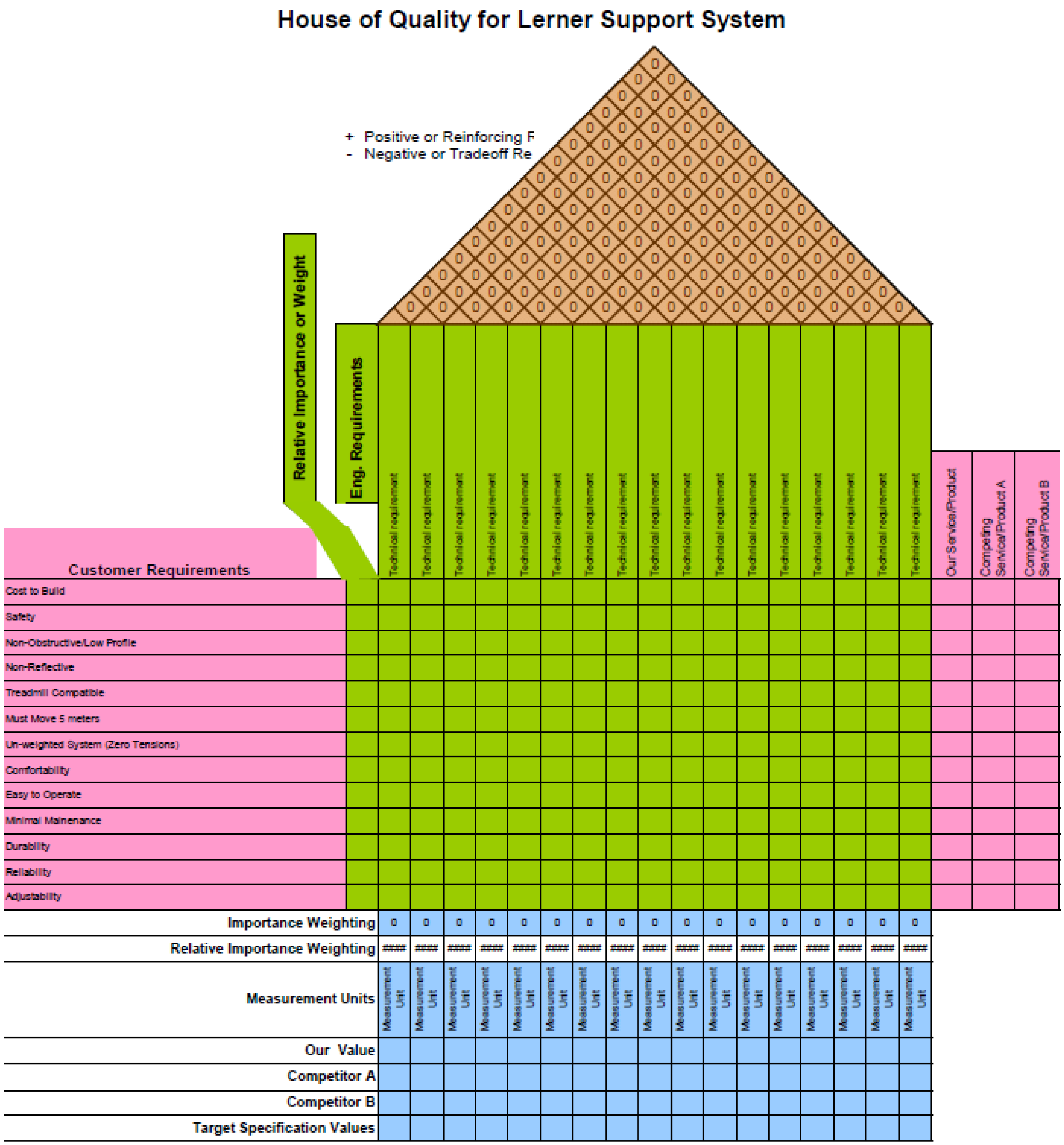


*Figure 18 : House of Quality*