Development of An IOT Sensor for Remote Health Monitoring:

Design and Marketing of a disposable and cost-effective humidity sensor system for adult incontinence products

This report documents the early development stages for an In-situ humidity monitoring and alert system for adult incontinence products. Using blue tooth-connected, smart sensor technology, and disposable materials, conceptual designs for a prototype and a plan to test its economic and technical feasibility were developed. A complete design specification was created based on market research and a Quality Function Deployment analysis of customer demands and industry constraints.

A major qualifying project submitted by the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science in Mechanical Engineering

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Chapter 1: Problem Statement

In order to improve comfort, cleanliness, and safety for elderly incontinent patients in long-term health care facilities, the development of a “smart diaper” has been suggested as a solution. This adult incontinence product can provide care givers with an early warning of low levels of patient wetness which could enhance the quality of life for patients and their families, reduce the risk of patient injuries due to slips and falls by mitigating fluid spills, as well as reduce the opportunity for patients to experience the development of decubitus skin ulcerations. A disposable product with a built in moisture detection system could perform the required task of moisture retention while facilitating a reduction in care giver workload, reducing facility noise levels through a reduced volume of patient bed calls, and help long term care facilities realize a systematic improvement in the health care accreditation process.

Chapter 2: Background

Sections 2.0: Introduction

In order to begin developing the diaper, the needs of the customer must be determined. This was completed through a survey of local nursing homes, assessing problems that may exist within the facilities, and addressing the importance of ameliorating these issues. Another factor that determines development of the diaper is an assessment of the target market and what other products exist. Researching the market for smart incontinence products, as well as learning what changes long term care facilities would like to make assist greatly in the development of a new, helpful product.

Section 2.1: The Customer's Needs

The main goal of developing a "smart adult incontinence product" is to ensure patients, their families, and their care givers may have a better experience when using such products. It is assumed that an incontinence product with a built-in moisture detection and wireless alert system could provide an early warning system to reduce the amount of time an incontinent patient had to wait to have their wet garment changed.

Due to the advanced age, and the accompanying issues of loss of bladder and bowel control of many nursing home patients, incontinence products must be changed frequently by the facilities staff member. Many nursing homes are understaffed, and nurse's aides are subsequently overtaxed with many patients to service simultaneously. Due to a similarly large number of elderly patients with some level of dementia or communication issues, aides typically rely on routine rounds and physical checks of incontinent patients to determine wetness. They rely heavily on incontinence products with high capacities, which can present comfort issues for patients. Automated moisture detecting sensor technology placed in an incontinence product could allow notifications to the staff whenever a patient needed to be changed, when the moisture level was still low enough to avoid liquid spills, discomfort or patient skin breakdown. Such a product could also speed up the time it takes to change an incontinence product, as well as prevent any other types of complications.

Incontinence products have been used in nursing home facilities for patients for many years. Older patients who are residents of nursing homes have a high rate of incontinence at a level which requires the use of incontinence products to avoid accidents. There are several types of incontinent products that can be used on adults. These include the pull up diaper, diaper briefs, reusable diapers, and incontinence pads. The pull up diaper most resembles common underwear but is thick and padded to absorb moisture. The diaper briefs usually include two tabs on the side to clip on. Reusable ones can be washed and reused. Incontinence pads are more like a napkin wipe which can be used with underwear or a regular adult diaper.

A smart incontinence product's main objective is to reduce risk of patient injury, discomfort, and skin breakdown due to long term contact with moisture. Failure to timely replace a patient's incontinence product can lead to decubitus ulcerations, also known as bed sores, an injury to the skin and underlying tissue resulting from prolonged pressure on the skin where pressure cuts off the blood supply to the skin and injures the surrounding tissue cells. (ShareCare, 2018) Often, bedsores are exacerbated when a patient remains sitting or lying in the same position for long periods of time – this is a common situation for patients in long term care facilities. Other risk factors include a poor diet, poor

hydration and medical conditions such as diabetes. Patients in long term care facilities have a high chance of developing these sores from sitting in wet incontinence products continually and for too long. According to a 2004 study by the CDC, 1 in 10 nursing home residents suffer from bedsores (Bed..) Although bed sores are treatable most times, sometimes they never heal leading to long-term pain and suffering. Elderly patients with other complicating factors can be difficult to treat. (ShareCare, 2018)

Section 2.1.1: Long Term Health Care Facilities

Research has shown a primary market for potential customers for a smart adult incontinence product could be long-term healthcare facilities. As a first cut focus group, data was gathered on local nursing homes in the Worcester, Massachusetts area to determine number of patients, percentage of incontinent patients and services provided. It was assumed that highly rated care facilities with high levels of customer satisfaction would be a good starting point for a study population. Table 2.1 is a list of the local long-term facilities that were reviewed for this study along with the facilities consumer rating.

Name	Rating
Wingate at Worcester	3.8/5.0
Colony Retirement Homes III	4.0/5.0
Dodge Park Rest Home	4.2/5.0
BrightStar Care of Worcester	3.75/5.0
Blaire House of Worcester	3.0/5.0
Beaumont Rehabilitation and Skilled Nursing Center	3.7/5.0
Christopher House	3.4/5.0
Lutheran Rehabilitation and Skilled Care Center	4.5/5.0

Table 2.1: Local Worcester Facility Names & Ratings

The total number of patients and the percentage of incontinent patients at the facilities surveyed are shown in Table 2.2.

Incontinence prevalence among residents of local Nursing Homes		
Facility	Total Residents	Incontinence %
Wingate at Worcester	140	25%
Colony Retirement Homes III	100	21%
Dodge Park Rest Home	62	19%
BrightStar Care of Worcester	N/A	N/A
Blaire House of Worcester	73	32%
Beaumont Rehabilitation and Skilled Nursing Center	65	29%
Christopher House	145	30%
Lutheran Rehabilitation and Skilled Care Center	93	14%

Table 2.2. Describes the percentage of incontinent patients residing at the long-term care facilities (in 2019) which were examined.

According to Rasmussen College, there are 14 different types of healthcare facilities served by medical professionals. (Sharecare, 2018) The patients most likely to need a smart incontinence product would be residents of long term care facilities who have been identified

as “patients whose medical needs are not severe enough for hospitalization but too serious to manage at home”(Sharecare, 2018). These types of patients are typically elderly patients, 80% of whom are over the age of 65 and have accumulated multiple medical problems over time, resulting in frailty and dysfunctions in the ability to take care of themselves. (Sharecare, 2018) These nursing homes offer a variety of products, mostly in the form of services, as shown in Table 2.3.

Long term care facility services
Living accommodations
Custodial care such as bathing, eating, and cleaning for the patients
Medication monitoring
Professional therapies, such as physical, occupational, and respiratory
24-hour emergency care
Social and recreational activities

Table 2.3. Long-term care facility services

In terms of physical products, healthcare facilities use a wide variety of medical devices such as instruments, apparatuses, or machines for their daily needs and functions.

Although every nursing home provides the same general care, each nursing home facility offers different specific services based on its staff. For example, a nursing home whose staff is filled with physical or occupational therapists will most likely offer better rehabilitation services. The products used depend on the patient's diagnosis.

While standard adult incontinence products are used routinely and heavily in almost all long-term care facilities, very few are using any kind of associated smart technology with these products. It is logical to assume that healthcare facilities such as those mentioned above, could benefit from a reliable product that could alert the care givers to a change in the state, or soiling, of a patient’s incontinence product. To achieve this, the product would have to correctly analyze humidity levels in the diaper to provide accurate feedback. The product should also be disposable to so as to reduce the risk of transmitting infections and optimize of ease of use and changing. None of the nursing homes included in the survey group of this study used any smart incontinence products.

Section 2.2: Market Synergy

Selling a smart incontinent product could result in a variety of opportunities for improving nursing homes and care centers around the country. There are many disposable humidity detectors, however, developing and marketing one that is combined with an adult incontinent product, could make a significant difference in the nursing community and raise the standard of care commonly found in long term care facilities, while also raising overall operational efficiencies. All this is likely to yield an increase in customer satisfaction and safety.

A smart adult incontinent product will be a product line for diaper companies already servicing the long-term care facility market. In moving away from a strictly at-home consumer product, the use of a "smart adult incontinent product" that uses information technology to function in a clinical setting would be a novel approach. An incontinent product with built-in sensing and alert technology would also be a new market for long term care facilities. The product would fit in well in the existing market structure since it base-product function (i.e. fluid absorption), and its look, feel, and handling would not change and would fit in with current product norms. In this modern age, there are many products and devices operated through smart technology (e.g. Bluetooth). As smart technology is already disseminated through almost every market including long-term care facilities in a variety of roles. Examples of this would be smart healthcare, a healthcare system that uses technology such as wearable devices, IoT, and mobile internet to dynamically access information, connect people, materials and institutions related to healthcare (Tian,2019). This product will most likely fall into the market for medical appliances or the medical device market. The United States also has the largest medical market in the world with a value of $156 billion. (SelectUSA) There are therefore many opportunities for this product to be developed and marketed if done correctly.

The product is designed to be used within existing healthcare facilities. No new facilities will need to be provided for this product to function properly. A feature included in the design that will aid in the prevention of the spread of disease will be making a disposable sensor.

The marketing can easily expand by catching interest through the health care centers. Already, marketers for humidifier detectors include chemical factories, refineries, and heating systems that create boilers. The sales techniques for this homecoming would be relatively similar but different. Again, the main goal is to attract the interest of nursing homes, which hasn't been done before when it comes to trying to market humidity detectors. Staff work will also stay the same because this product will simply help make the nurses' jobs easier and more efficient.

Section 2.3: Environmental Scan

Success when entering a new market is best supported by knowledge of the external factors that may affect the business, and an effective plan determined from such factors. An environmental scan identifies these factors, which can include any competition, economic trends, technological advancements in the field, and legal regulations, to name a few. Adapting to a changing environment is important for a business, so performing an environmental scan is essential to foster success. A good environmental scan will allow the business to recognize threats in a changing market before they become greater issues and adapt their strategy accordingly so that they can secure long-term success.

Section 2.3.1: Market Attractiveness

This dimension helps determine the attractiveness of the market by analyzing the benefits a company is likely to get by entering and competing within the market. Several factors

are studied. These include the size of the market, its rate of growth, profit potential, and the nature, size and weaknesses of the competition within the industry.

Section 2.3.1.1 Long-Term Care Facility Market

The size of the long-term care facility industry has drastically grown over the last few years. Demand for long-term care facilities are very strong due to the world's rapidly aging population. According to the World Health Organization, "the percentage of people over 60 are predicted to grow between 2020 and 2050." (Long Term Care Facilities Industry. 2019). Because of this, a growing number of countries with national health insurance are encountering a high increase (around 15%) in demand for long-term care homes. As far as the United States, there are 89,000 nursing homes and long-term facility establishments that are rapidly growing annually. Combined, single location companies and branches of multi-location companies collect a combined revenue of $250 billion. (Long Term Care Facilities Industry. 2019). Even though the size of this industry is thriving, it is challenging for some locations in certain states (e.g. Massachusetts) to gain tax money in order to update their facilities. In conclusion, the industry and has vastly grown from the past five years. However, when it comes to certain areas in the nation, some are more financially stable than others.

The long-term healthcare industry's profits are currently at an all-time high. (A Thriving Market, 2019). This is because incontinence care products are being used more and more in a variety of medical centers. The adult brief industry is focused on spreading awareness on proper usage of proper incontinence care products. By industries doing so, the structure of the industry itself becomes more prominent. The adult brief market and industry is based off innovation and progress. Over the past decade, these types of products have grown from solely being in the healthcare industry, to being a mainstream product. Companies like *Drylock Industries*, believe that adult incontinence products, "should not leak, not be observed under clothing and not release any odor." (A Thriving Market, 2019). As time goes on, technology progressively was combined with the incontinence care product industry. As a result, technological improvements have allowed these products to become thinner and portray a better performance. Thus, why there are multiple companies in other countries who have such a product we are trying to create. The next step for the structure of this industry is to combine the technological advances with nursing homes.

A product life cycle consists of 3 parts, its growth, its maturity, and its decline. This is important in the healthcare industry as users need to know how long a product will last and how reliable the product is, as the product will be affecting their health. In the growth phase, your product starts to sell as the public is increasingly becoming aware of your product and its value. At maturity, your product is at the height of progression and will have competitors fighting for the top sport. Finally, the decline stage is when product sales go down and the product loses its value. In the healthcare industry, customers are always in need of the best equipment to best take care of their health. Determining a product's life cycle can determine how successful your product will be. As the number of adults over the age of 65 continues to

rise, more beds are needed to house them. The long-term care facility market is currently in its mature stage, housing the "baby boomer" generation as well as older generations. This market will continue to slowly grow as the annualized rate that adults are expected to turn age 65 continues to grow.

There is and will always be a high demand for the long-term healthcare facilities. Custodial and skilled nursing care is a necessity just like food and shelter, therefore the demand for it is big compared to other industries. According to AMN Healthcare, the greatest driver of the healthcare industry in America is the aging population. This aging population uses the most healthcare and receives universal coverage through Medicare. (AMN Healthcare)

Costs related to treating elderly patients is expected to reach 6% by 2020 (HLM). According to Health Leader Media, this is the first time it had reached 6% since 2016. The major inflators for these costs include prescription drugs, chronic diseases, and meatal health services. The major deflators of the costs were expansion of work clinics and maximization of health benefits packages. Along with the actual Healthcare, employment demand in the healthcare is also high. Due to rising patient demands, there is more need doctors, nurses, and physicians, especially due to the clinical workforce getting older. (AMN Healthcare)

"Market segmentation is used by companies across industries to group their customers into diverse groups based on their similarities and to analyze each group separately for identifying key factors affecting their behavior."(Business Wire, 2019) Healthcare market segmentation is a relatively new concept. It provides insights into the behavior of healthcare consumers in an environment where healthcare is moving rapidly towards patient-centered care which is premised on individuals becoming more active participants in managing their healthcare plans.

Segmenting the healthcare market brings about four benefits (Business Wire, 2019):

- Patient engagement allows the care provider to compile information on a variety of patients so that care is improved for specific patients and overall.
- Healthcare marketing can be improved by learning about patient preferences and how the target audience will respond to different messages.
- Service distribution strategy can be improved and used to locate necessary providers or services by learning what consumer segments are most prevalent in different communities.
- New product or service development can result from companies learning how the consumer responds to certain messages or models of care and filling any voids that pop up.

Section 2.3.1.2 Adult Incontinence Product Market

With a 2.9% annual predicted rise in adults over the age of 65 from 2019 to 2024 comes a rise in incontinence levels amongst these this older population due to conditions such as diabetes and strokes. As a result, over this same time period the market for adult incontinence products will rise as well at a rate of 1.2%. In 2018, the industry for adult incontinence products brought in almost 9 billion dollars in revenue (NWI, 2019). Since 2014 the industry has steadily

increased its revenue each year and with major players such as Kimberly-Clark and Essity introducing new changes to make the products more appealing, the industry's size will continue to grow as the need for it grows as well. (Jack Curran, 2019)

Although the industry's profitability was already well above the average for the manufacturing sector, its profitability has continued to rise. Stagnant price points over the past few years have caused the industry to consolidate, bringing the Kimberly-Clark and Essity, as well as Procter & Gamble, more revenue with there being less competitors. As the world's older population grows, demand for incontinence products will also rise. This can be caused by conditions such as diabetes or strokes, or by the natural aging process as the nerves and muscles in the bladder deteriorate. Another possibility, especially for those that may not be able to control their urine at night, is that heart conditions may cause a buildup of fluid in the body that may only be released when laying down (NIH, 2017). If someone has arthritis, this could make getting up a great challenge, let alone multiple times in one night. The solution of briefs, in particular, curbs most other issues that incontinence may cause such as soiled clothes or bedsheets.

In order to meet the rising demand, labor and wage costs have also risen. The largest cost for the industry is the purchase of raw materials, mainly the nonwoven fabric outer and the absorbent inside of the brief that are made from plastic resins. These costs are expected to decrease over the next 5 years as plastic material and resin cost are predicted to decrease at an annual rate of 1.4% (Jack Curran, 2019). As this industry is well established and has a high level of competition, it is in the mature stages of its life cycle. Due to this competition, the top competitors have expanded greatly to stay on top with Procter & Gamble operating in over 40 countries.

The market continues to grow for those over the age of 65. In addition to regular disposable diapers for those over 65, a new "smart" brief has been developed by multiple companies that make being a caretaker for others even easier. Past market activity as well as predictions for the future can be viewed by the graphic below.

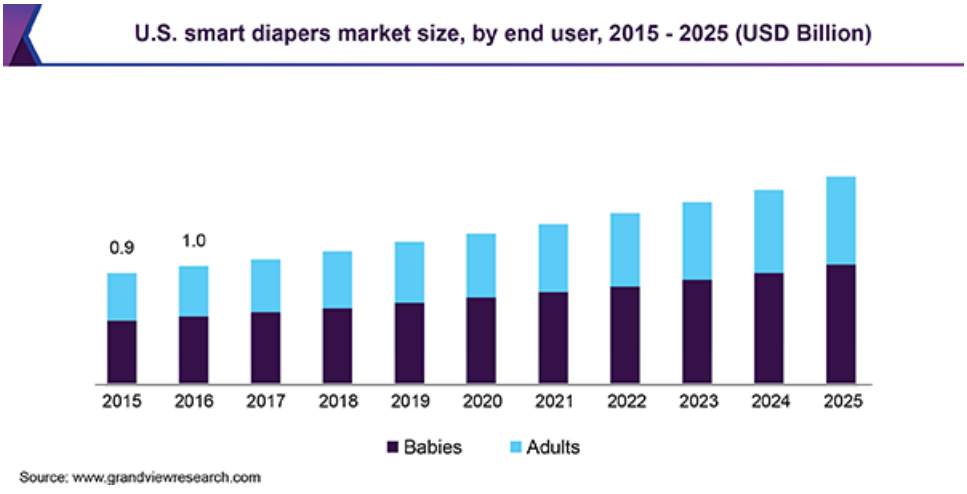

Figure 1. Reflection and Forecast of Market

The technology of the smart diaper is currently available on the market. Brands like Huggies and Pampers have used the technology to focus on smart diapers for babies, whereas Opro9 has ventured into the adult smart diaper market. Each of the diapers features a reusable sensor, connected to a user's smartphone via Bluetooth, that is attached to the diaper.

A problem with this technology is affordability. The sensor used for Huggies' diaper costs $249 alone (Waters, 2019), presenting an impractical solution to the issue of incontinence due to many Americans being unable to afford regular diapers (NIH, 2017). Pampers' line of smart diapers also comes with an issue: it will only notify the parent if the child has urinated. Pampers' diapers will not be able to detect bowel movements of the child. If developed in adult sizes and introduced to the setting of a nursing home, both solutions would prove impractical either due to price or the inability to thoroughly notify the user of the smartphone application when the diaper has been soiled. Opro9's product is more affordable at around $50 but is not reliable due to discontinuity in the connection between the application and the sensor.

Figure 2. Opro9's Smart Product

Section 2.4: SWOT Analysis

In order to further analyze the market and determine the potential outlook for success of a smart adult incontinence product, a SWOT analysis was performed. A SWOT Analysis “helps develop a full awareness of all the factors involved in making business decisions.”(Schooley) Through a SWOT Analysis, a company's chance of economic success can be assessed by comparing the relative strengths of advantages and disadvantages resulting from both internal and external factors. By analyzing each of the Strengths, Weaknesses, Opportunities, and Threats, a better understanding the product’s performance in the marketplace. a(See Table 2.4 below)

By analyzing the strengths, we realized the greatest strength of our product would be its extra value. We would be providing a sensor for diapers that would be easy-to-use and disposable. This is a strength since it puts us at an advantage over other companies whose sensors aren't disposable. Therefore, any resource put into pushing and branding its value would be a strength. This may include specific material and technology suppliers. The value proposition of the product is also able to serve a large customer base of nursing home patients meaning our product will be a customer need.

Many weaknesses can be derived from our market plan. As a new business manufacturing a product already known to the market, conflict is bound to arise when marketing the product. Also, as a new product in a big market, we are bound to have different business processes and strategy issues without a effective marketing plan.

There are many opportunities for our product. The first and major opportunity is our products' large market. In the United States alone, there are approximately 15,600 nursing homes housing about 1.4 million patients. (Schooley) The market being large means there is a high need for a product such as ours. This product when entered the market will fall under the medical device umbrella entering this market would allow marketing strategies tailored to nursing homes and healthcare facilities to flourish. The large market also opens opportunities for partnerships and business deals. Due to the nature of our product, our product will be able to be sold business to business (B2B). Marketing the product to large businesses will allow the customer to purchase in bulk at a subscription rate. This price will be available from the manufacturer’s website and through direct consultation with the manufacturer, as well as through any distributor that sells the product. This product being made but not widely known has the chance to evolve with any market trends.

Although there are many opportunities, there are also many threats. Our product has many competitors already making products that solve the same problems that our product does. Lumi by Pampers and Opro9’s Smart Diaper. In order to make the product stand out from the competitors, the marketing will highlight the disposability and lower price of the product, showing a clear advantage over the two competitors and their previously described shortcomings.

Strengths	Weaknesses
• **Product Values** • **Provided Diaper and Sensor for Incontinence** • **Disposability** • **Customer Need** • **Large Customer Base** • **Low Price**	• **New Product and Market Entrance** • **Depending on success determines when business may break even** • **No Specific Business Process**
Opportunities	**Threats**
• **Large Market** • **Over 15,000+ Nursing Homes to distribute to** • **Partnerships and B2B** • **Lots of room for expansion**	• **Lumi by Pamper** • **Opro9's Smart Diaper** • **Product are already in market and succeeding in their own right**

Table 2.4 SWOT Analysis

Chapter 3: Goal Statement

Our goal is to develop an In-sit humidity monitoring and alert system for adult incontinence product. Using information technology and disposable materials, we will provide conceptual designs for a prototype design to perform to customer specifications developed through a QFD analysis of customer demands and industry constraints. Research will be conducted on the marketing of the product.

Chapter 4: The Voice of the Customer

Section 4.1: Introduction

In order to determine the most important, popular and saleable characteristics into our design, we need to understand what customers would value most in our product. By performing a Quality Function Deployment Analysis, we can determine which characteristics of the design would most entice customers to purchase the product. “Developed by Yoji Akao in Japan beginning of 1966, Quality Function Deployment (QFD) is a process and set of tools used to effectively define customer requirements and convert them into detailed engineering specifications and plans to produce the products that fulfill those requirements.” (Home) With an effective QFD analysis, we will be able to convert customers demand into design targets.

For this project, we will be creating House of Quality, a sub-process of the QFD that analyzes customer desires for the product and its development and determines which capabilities and resources currently exist or need to be added to meet the desires of the customer base. The QFD process will help organize and prioritize the product features most important to the potential customer base. The first step in the QFD process is to identify the needs, expectations and preferences of the customer. This can be achieved by attaining the Voice of Customer (VOC). For this study, customer preference data was gathered through interviews and surveys. Through the analysis and evaluation of the interviews and surveys, the needs and demands of long-term care facilities were determined.

Section 4.2: Customer Needs Survey

With the completion of initial research targeted at the needs of the nursing home community relative to the management of incontinent patients, a survey instrument was created to help get more statistical numbers from different staff members. When this project was initiated, the goal was to meet with local Worcester nursing homes and set up in person interviews with them about incontinence factors, communication systems, and their opinion of the product. However, after only receiving feedback from a couple companies prior to the implementation of social distancing accompanying the COVID-19 pandemic, it was decided it would be best to conduct a quick and efficient online survey. After reaching out to more than 100 homes on the east coast a small, but significant number of responses were received. The survey was designed to be anonymous to enhance the quality and unbiased nature of the feedback on the quality of internal communication systems the potential benefits to patients of a potentially higher cost solution than what is currently available.

This survey consisted of 17 questions that were multiple choice or scaled questions. Each question was brief and concise for while ensuring that reputable data was gathered. By conducting interviews and surveys of nursing homes, needs that were most highly valued were collected in conjunction with the perceptions of how the product could fulfill those needs. If the quality of living was improved in nursing homes, the risk of remaining in soiled briefs for an extended period of time would be reduced. One of the main focuses aside from creating our sensor hoping the humidity chip could help with staff efficiency. If we were to make the brief and/or sensor disposable, it would be easy and accessible for staff to manage. Also, the nursing homes we collected data from agreed that they would pay the same as or less than $1 for a disposable sensor if one were to be made. This helped us get somewhat of a cost analysis plan. From the survey we learned that the sensor could be able to reduce

risk of sickness, increase the safety of patients (due to fast response time), and provide instant alerts when the briefs are dampened. Because of this, clinical care efficiency can be increased. After talking with a nearby nursing home, it was concluded that noise is a big factor for staff. Reduction of noise is significant because it won't disturb patients if they are resting and will still be able to silently notify the nursing home staff.

The customer needs survey was also very helpful as far as coming up with basic design factors for the chip itself. A quick and strong signal was requested by the nursing staff to the sensor. That way, a signal can be sent to the staff members as soon as the patient requires care. Chip water saturation was also another important factor that came up in the survey. It was recommended that we make sure the chip can withhold a fair amount of moisture before sending the signal to the sensor. Also, body temperature (100 degrees Fahrenheit) needs to be considered for the sensor and chip itself. The sensor must be able to quickly detect change in temperature and humidity of the brief.

Section 4.3: QFD Analysis

The QFD process helped determine which demand customers value most by ranking them by level of importance. Ranking the value of our customer requirements helped the design team recognize the competitive edge over competitors. By ranking them the customer needs, it can be seen how those needs compare with competitors to determine advantages and disadvantage based on product value. With the demands and the rate of importance calculated, the quality characteristics of the product were then determined. Next the design parameters to be prioritized were calculated. Once determined, a correlation was made between the customer needs and the products quality characters – that is those features and specifications which can be controlled in the manufacturing process by design. This allowed the ranking by importance of the characteristics. Determining this statistic allowed the team to identify the key parameter that our design will focus on and our customer will value most.

		Quality Characteristics					A	N	Plan		P	B	C	D	
		Small Sensor Size	Long-lasting Battery	Quick, Accurate Notification	Sensor Operating Range		Rate of Importance	Company Now	Opro9	Pampers	Plan	Ratio of Improvement	Sales Point	Absolute Weight	Demanded Weight
Customer Demands	Improved Quality of Life	9	1	9	3		4	5	5	5	5	1	1.5	6	0.208
		1.872	0.208	1.872	0.624										
	Improved Clinical Care	1	3	9	9		3	3	3	2	5	1.7	1.2	6	0.208
		0.208	0.624	1.872	1.872										
	Ease Management of Care	1	1	9	9		4	4	5	5	5	1.3	1.5	7.5	0.26
		0.26	0.26	2.34	2.34										
	Cost-effective	9	1	1	1		5	4	3	1	5	1.3	1.5	9.375	0.324
		2.916	0.324	0.324	0.324										
	Total	5.296	1.416	6.408	5.16	18.28					Total			28.88	1
	Percentage	29	7.7	35.1	28.2	100									
	Company Now	9	1							Main Correlations					
	Opro9	3	9	9	9						9 = Strong Correlation				
	Pampers	9	9	9	3						3 = Some Correlation				
	Plan	9	3	9	9						1 = Possible Correlation				
							Sales Points = 1.5, 1.2, or 1								
									D = A * B * C				B = P/N		

Figure 4.3. QFD Table

Section 4.3.1: QFD Results

After a full QFD Analysis, we were able to identify the highest customer demands and characteristics that should be prioritized when designing the product. Based on the QFD analysis, it was determined that our customer demands included “improved quality of life” and “improved clinical care”. Based on these two demands, we decided to compare how the features and value of our product fulfilled this demand. The purpose of our product is to sense feces so the patient may get their adult diaper cleaned as soon as possible. This was explained as it prevents and reduces chances of sickness and infection therefore improving quality of life. The product has a silent alarm that alerts the nurses or whoever is in charge without disturbing any peace. This also fulfills our highest quality characteristics of a “quick and accurate notification”.

Section 4.4: Potential Incontinence Solutions with Benefits

During the process of trying to market this project, customers may wonder, “how do we know the product is working?” The purpose of this product is to help notify the nurse quickly and efficiently that the patient’s diaper should be changed. The humidity detector will send a signal to the nurse’s mobile device to quickly send a signal and notify them that there is a change in moisture. Of course, the product will have to be tested as far as quick response time as to how prompt the disposable device can show a difference.

The product can be used to ease physical and emotional stress. The product will prevent infections or other conditions that may arise from continually wearing a soiled diaper. The product will also emotionally aid the nurses in these facilities by decreasing noise pollution and giving notifications via mobile phone application, calming the nurses and fortifying their mental health.

This product has the potential to provide comfort and efficiency for both nursing staff and patients all around the world. We hope to provide quick response time by the nursing staff, which leaves satisfied patients. Not only will the living residents be content, but this can also help boost sales and reviews for nursing homes. Another issue that this product can hopefully solve is ambient noise. After our interviews with the nursing homes, we learned that admissions and nursing staff specifically is not a fan of the annoying and loud beeping noise systems make when a customer needs help. Efficiency in the nursing home is key because there are some patients that require round-the-clock care. Just by having this new communication device, nurses will be able to take care of each patient quicker. This can also reduce illnesses and diseases simply because this means that patients will be changed quicker... not allowing them to sit in their soil for long periods of time. These benefits are listed in Table 4.1.

Table 4.4
Quick response time
Satisfied patients
Organization for the nursing staff
Boost scores on nursing home reviews
Reduce illnesses and diseases
Sound alert reduction

Potential Product Benefits

The QFD process also revealed that current products for adult and baby diapers marketed with humidifier detectors do not fare well from a value perspective when compared against the customer need, presenting this team with a market opportunity for its product. While most of them are in other countries, they haven't necessarily moved to worldwide consumption. The market for the companies that were mentioned in the previous sections were mostly for individual consumers. These products are reusable and have been recognized as uncomfortable to customers. Since they are seen to be used more than once, the diaper eventually wears out and provides inaccurate readings. Some of the providers of these products meet some needs but not all needs of the consumer. DiaperSens from the company ElderSens employs a reusable sensor. This feature could foster the transmission of disease and possibly decrease patient safety. Similarly, the Opro9 Adult Diaper also employs a reusable sensor. Reviews of this diaper revealed that correct and timely notification were a rampant issue as well as a myriad of false alarms.

Section 4.5: Product Features for Smart Adult Incontinence Product

Based on the results shown through our QFD Analysis, the most important product features were determined for the smart adult incontinence product. . For performance, our product will have accurate temperature and humidity readings. It will have immediate alert when activated to allow for quick response times. It will also have a long-lasting battery life giving patients and nurses rough time to use and dispose of product. Its features include a humidity chip detector and a wireless connection device. These were the two main features made to fulfill the top customer demands. Other features include the device being small and portable. The product reliability includes its quick response time from the nursing staff to change, providing comfort and quickness for patients. The product's durability will include choosing a material making our product safe enough to be disposed. The product will be able to be slipped into a diaper without providing discomfort to patients. The aesthetics will be design were its most comfortable for our product, mainly because we our more focused on its function and effectiveness rather than how it will look. Packaging will small and disposable. Packages will be sent out by the bulk to nursing homes, so our packaging will accommodate for that. For the cost, we determined our customers are willing to pay $1 or less for the sensor. Based on how much it cost it manufactures the product, a price acceptable to customers can be determined.

Performance	• *Accurate temperature and humidity readings* • *Immediate alert when activated* • *Long-lasting battery life*
Features	• *Humidity chip detector* • *Wireless connection to communication device* • *Small* • *Portable*
Reliability	• *Quick response time from the nursing staff to change, providing comfort to the patients*
Durability	• *The purpose of our new briefs is so that it can be comfortable for our customers.* • *Unlike our competitors, our briefs are going to be a comfortable fit with our disposable humidity detector in a pocket of the diaper.* • *Detector will be accurate, and the briefs will be able to last longer.* .
Aesthetics	• *Efficient way to provide easy comfort to the patients.*
Packaging	• *Efficient and small packaging for the chip sensor* • *Will be packaged out and sent to nursing homes in large bulk*
Cost	• *Customers are willing to pay $1 or less (per sensor)* • *Manufacturing cost is going to be around $___* • *Product is being sold by the bulk to companies which could cost around $____*

Section 4.6: Design Specifications

The diaper itself will be nonwoven and constructed of a polypropylene front and a polyethylene back that will render the diaper nonpermeable. The absorbent material in the diaper will be composed of a polyacrylate resin. The sensor will be attached to the diaper in a hybrid internal position and will be discreet as the sensor's sleek profile measures in at 2 x 1 x .25 inches. The sensor is made of plastic, and will feature an antimicrobial coating, keeping it safe and germ free while it operates at 5 – 60 degrees Celsius and is accurate from 20 – 80% relative humidity. The product is powered by a 1.8V battery supply and has power up and measurement ability within 1 ms.

Section 4.7: Product Realization

During this project, there were multiple designs that were explored for the location of the moisture sensing chip and how it can be incorporated comfortably in the customers' brief. Below is a breakdown of each orientation and design of the product. Presented are three designs which all meet the needs of the market, distribution companies, and customer.

The first design that was analyzed is the external mounting option. The humidity chip will be located on the outside band of the brief. The chip itself will be housed by a band to prevent any external exposure. If this option were to be chosen, the cost could be low due to the lack of necessity for modification of the actual incontinence product. However, there would be a possibility of inaccurate readings and the sensing chip would require a high gain of sensitivity, reducing accuracy and repeatability (from the chip). Also, the chip could potentially fall off if the patient were to lay down resulting in too much movement.

The next design that was considered is the internal mounting. This includes a built-in pocket on the inside waist band of the adult brief. The sensor chip will be able to provide high accuracy readings because it will be on the inside lining. However, the brief will require design modifications and the cost of this design will be increased.

The last design that was constructed is the hybrid internal option. This sketch includes gauze-like material to house the chip along with adhesive lining to stick onto the brief. This design would be most practical because, due to the adhesive, the chip can be stuck anywhere on the brief. Easy accommodations to the chip can be accessed and made if needed. Also, no modification would be necessary towards the adult brief... which helps cut initial costs. Nevertheless, additional materials and components will need to be acquired for this design. There is also a high chance the accuracy of the sensor chip will go down due to the various positional options in the brief.

After analyzing each design stated above, we concluded that the best design for our chip would be the hybrid internal. Even though it had some clear negatives, this design would be the most cost-efficient and accurate way for our customers.

Section 4.7.1: Sketches

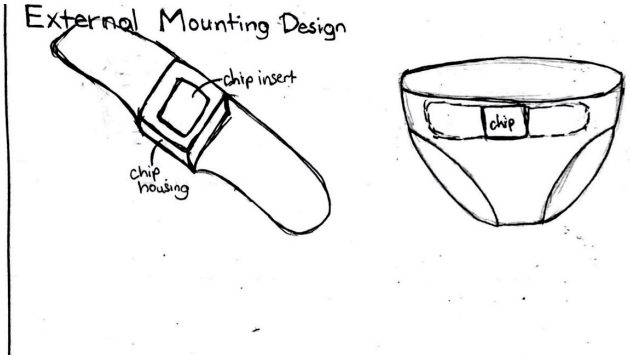

Figure 4.7.1: External Mounting Design

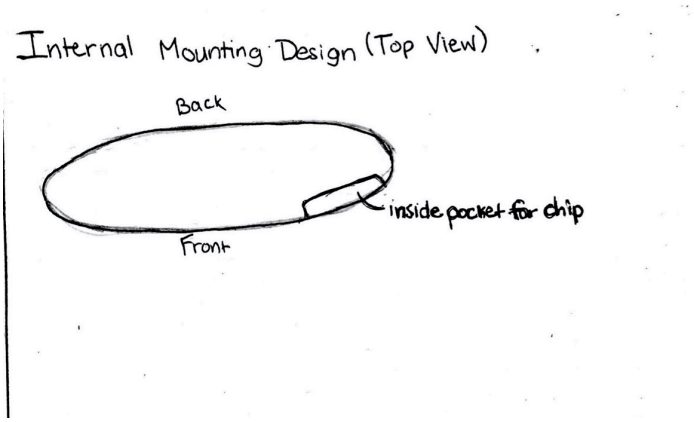

Figure 4.7.2: Internal Mounting Design

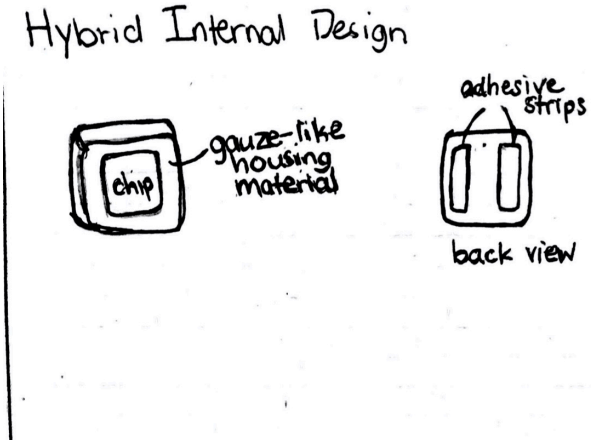

Figure 4.7.3: Hybrid Internal Design

Section 4.8: Manufacturing

Manufacturing is an important part for this project and its next steps. Regardless of which design ends up being chosen, the first step would be sourcing components. Each design we have created requires parts that need to be put together. For example, the hybrid internal design we recommended in the previous section would require we at least three components. The gauze-like material, chip sensor, and adhesive would need to be gathered from other companies.

Once the product is created, the next step would be distribution. After doing research on our long-term care facility market from our project, we were able to get a better sense of who would be interested in our product. This product should be created to be distributed by bulk. Once created, the sensor should be distributed to nursing homes around the country. This will then allow the sales to be easily tracked compared to if we were to make this product open to family homes.

Another part to manufacturing would be the facility and its layout. The location of where and how this product is made is very important in the next step process. Once created, a very proficient system must be created to rapidly product bulks of this product. Along with the facility layout, manufacturing operations and equipment needs to be taken in consideration. For fast production, it would be recommended to use a factory conveyor belt to help assemble the sensor chips to the gauze housing.

In addition, another important factor that would go into the manufacturing assembly would be the labor requirements. These would entail each part for our project being put together. Once assembled, the labor portion would include packaging and shipping out to any nursing homes that are interested. While manufacturing plays a huge role for our product, the estimates of production volumes and manufacturing costs should always be monitored. This is suggested just to make sure no money is lost during the process of making the sensor chip and our market is still rapidly increasing for the want of this product.

Section 4.9: Distribution

For our product to reach the nursing homes, we need to identify the key distributors that would be able and willing to sell our product. Due to the medical nature of our product, we will be acquiring distributors in the medical device industry. According to the Health Industry Distributors Assocation (HIDA), Healthcare distributors serve more than 295,000 locations nationwide, delivering the right supplies to support nearly 100% of patient procedures. Based on an article “The Top 100 Distributors of Medical & Surgical Equipment, Devices, Instruments & Consumables Worldwide” published by Research Facts ltd, here are a list of potential distributors that could provide a viable world-wide distribution network for the smart adult incontinent product.

- SSS Australia
- Transmedic Pte Ltd
- Al Mazroui Medical & Chemical Supplies
- Medtechnica Ltd.
- Cyprus Pharmaceutical Organization Limited
- EG Medical Systems
- Fannin
- AA Laquis Ltd.
- McKesson Corporation
- Century Medical, Inc.
- IDS Medical Systems

Chapter 5: Conclusions and Future Work

Section 5.1: Conclusion

This section is provided as a summation of the work completed for this project and to lay out a template for others who may wish to continue the work.

Section 5.1.1: Conclusion on the Market

Seeing how vast and growing the medical market is, as well as its constant need, our product has much opportunity in this market. This products target audience of nursing home patients will always

find value in this device. Therefore, with an effective marketing strategy to correctly target these nursing homes will effectively showing the value of this device will make this product successful on the market. Since our aim is to sell to B2B business, effectively preparing and planning on how to target and retain these businesses will be our next goal. Seeing how quickly technology is advancing and how we are moving more into a digital age by the day, finding ways to market online to businesses with methods such as inbound marketing tactics would be a great plan of action. Other ways of marketing to B2B businesses would include (bluecorona):

- A great website
- Social media marketing
- Video marketing
- Content marketing
- Search engine optimization (SEO)
- Pay per click advertising (PPC)
- Event marketing
- Affiliates and partnerships
- Remarketing
- Marketing automation (including email marketing)

Section 5.1.2: Conclusion on the Device

In order to finalize the design of the product, a first prototype needs to be made. The device in its current stage is designed to work well but still needs to be tested to ensure the proposed designs are the most efficient way of producing the diaper. The most popular materials for the front and back of the outer of diapers are polypropylene and polyethylene. The absorbent polyacrylate inside the product can be modified, though, in order to make sure that it does not produce an odor when soiled. This can be done by removing the vinyl ketones (5-methylhex-1-en-3-one) that were initially used to prepare the polymers (ScienceDirect). The sensors have been tested and are known to function properly, but correct position on the diaper needs to be determined. The design states that the sensor will be mounted in a hybrid internal position, but this design makes the positional variation's effect on accuracy and quickness a possibility. The device has been designed well to fit the customers' needs, but in order to work out any kinks and render the design flawless then a prototype will need to be created.

Section 5.1.3: Filling in the Gaps

Coming to an end, there were some important factors that were left out of this project as time went on. In the beginning stages, there was a lot of research done about the adult brief market and how its increased overtime. Since this project will possibly be picked up within the next few years, it is recommended that these market numbers are re-analyzed. Due to the rise and drops of stock markets, these numbers could have significantly increased or diminished. Before doing research on see which nursing homes would want to invest, it is recommended that the structure of the industry is reexamined. Next, the design we recommended in Section 4.7 for the product realization should be studied and looked over before taking any further steps. Another part of the project that needs to be done is creating a prototype. Beforehand, doing research on the required material for creating a housing for the sensor is recommended. It needs to be feasible enough to create along with a reasonable budget. Once a prototype is created, the next step would be finding an out-of-state nursing home with financial stability that would be interested in this product. As we were doing research and interviewing

nursing homes, it was apparent that multiple nursing homes' communication systems needed to be updated. However, local homes were unable to provide funding for a new system such as ours.

Section 5.2: Future Work - Feasibility Study Plan

In order to continue with this project, it is recommended that the sketches are taken further. Since we were able to establish what design and chip orientation will beast suit our market, more CAD design models should be created. These computer designs should have the detailed dimensions as seen in ours along with different variations with where the chip can be placed within the brief. It is also recommended that computer thermal tests should be run through CAD to help the group understand how much heat the chip can withstand.

The next step would be 3D printing a rough prototype of the housing for the chip, along with researching how the gauze-like material can be used to create a pocket. Once the prototyping phase is complete, a re-designing period should take place to ensure the best accuracy from the product. Durability will also play a huge role in this project and should be analyzed for the chip. A manufacturing plan for how the chip along with the brief will be constructed, put together, and distributed should be re-analyzed and finalized.

Lastly, the economic feasibility plan should also be analyzed and re-evaluated. Seeing that this project could get picked up in the later years, the economic feasibility plan should be looked over and potentially redone. Also, the design specifications should be refined. Throughout this project, there was an extended amount of research put into this project. Continuing to do research on adult brief companies, the current market, nursing home facilities, and the neighboring companies will always be helpful no matter the stage of the project. Also, staying in communication with nursing home staff members provided us with important information to help design possible solutions.

For this product, our business proposal is broken down into segments. As it will be seen further in the paper, our design is composed of a few parts. The adult briefs will be collected from an outside company. Even though we do want to make sure that the briefs are comfortable for the customer, we also want to focus on the utmost accuracy from the humidity chip. By multiplying the number of adult briefs from an outside source with the number of humidity chips created, it will get us our smart incontinence product. Another addition to our business model would be the protective housing for the actual chip. The band would have to be created so it can comfortably fit in the brief without irritating the customer. Once our full product is created, the next step would be trying to sell them to long term care facilities. While trying to reach out to nursing homes, we did encounter a couple barriers. Trying to get our product in nursing homes would be challenging because they already have a set arrangement for dealing with brief comfort and customer communication. After visiting facilities in Worcester, Massachusetts, we learned that these nursing homes don't have the money to invest in a whole new system.

Section 5.2.1: Future Work - Technical Feasibility Plan

Our product is a humidity sensor design to be used in conjunction with diapers to aid with incontinence. Its features include and accurate temperature and humidity reading sensor that immediately alerts when activated through wireless Bluetooth connectivity. The device is relatively small and portable with a long-lasting battery life. This product has not already been on sale and without the right distributors and customer demand, it will not be marketable. There are products as such that serve

the same purpose, but none with our specific design and usage. The best way to protect the product from competitors is to stick to the uniqueness of our design. Our differences in our design compared to our competitors if focused on will really show the value of our product.

The value strengths of this product that distinguishes it from its competitors and benefits our customer users are as followed:

- Disposability
- Silent Alarm Technology
- Bluetooth Technology
- Small and Easy to Use

There are also several resources needed to effectively produce and provide out product. The sensor required for our product plays a huge role in this project. This component is designed to work with the humidity chip and send accurate signals to nursing home communication systems. Once the chip detects an uncomfortable amount of humidity in the patient's brief, the sensor must quickly be able to send the signal to notify the nurse. Another important resource that needs to be considered is plastic or gauze like material. This material is required to help house and protect our sensor chip. Although we do want accurate and efficient readings from the chip/sensor, we also want to make sure it is comfortable for our customers to rest on. The last significant resource needed is a software technology system. This component will be used to help send the signal from the adult brief to the nursing staff. In order to have accurate efficiency, it is recommended that this component is Bluetooth.

Experiments:

1. Placement and mount type of sensor within diaper: Place the sensor in multiple locations in and around the diaper, then test by "soiling" diaper with average volume of liquid (water) that an elderly person would produce. Record results, then determine which location gives the quickest and most accurate reading.
2. Bluetooth range (Non-open field): With the sensor placed in the diaper, visit a nursing home (place we are marketing to). Connect the sensor to iOS device, determine the maximum area/distance covered by a given Certified Nursing Assistant (CNA), ensure that the sensor can reach that specified distance, then continue to increase the distance within the nursing home until the signal is lost. Repeat multiple times to precisely determine maximum range of sensor. Repeat with Android device as well, if necessary.
3. Humidity detection range: Using controlled amounts of water, determine minimum and maximum amounts of humidity that sensor can accurately detect within the diaper, as well as how quickly the minimum amount is reported to the connected iOS or Android device. Repeat multiple times.

Section 5.2.2: Future Work - Financial Feasibility Plan

Our product has much potential with a proper business plan and an effective marketing strategy. Due to the lack of business portfolio for our product, there are lots financial components that couldn't fully be analyzed. This includes potential sales volume, production volume, pricing structure, return on equity. With the research and data given, a humidity sensor package that include a battery and Bluetooth connectivity would approximate around $10. By analyzing the price structure with the

approximate price, we would then need to analyze and put into account the manufacturing, distribution and operating expenses before setting a specific price for our customer demographic. For price sensitivity, we want to be sure that the customers, in our case the nursing homes, are willing to pay our price for the product. Based on our research, it was determined that most nursing homes were not willing to pay more than $1 for our sensor. Other components needed to be analyzed with a complete financial feasibility study would be product survivability, Starting Operation Expenses, Breaking Even, and external finance.

Chapter 6: Annotated Bibliography

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Nursing Homes

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Appendix A: Health Care Facilities

The *Wingate at Worcester* specializes in ventilator care. This home focuses on care for people who need help breathing. They have upgraded machines that help customers receive oxygen to their lungs, remove carbon dioxide from the body, and help breathe for elders who might have lost ability to do it on their own. Wingate is also very good with cardiac rehabilitation, nursing people's bodies back to healthy respiratory systems. This home does seem more of like a rehabilitation center, seeing that they aren't the best when it comes to long term commitments with elders.

Located in Central Worcester, the *Colony Retirement Homes III* provide very spacious homes and rooms for residents and families. This already will help boost sales for this retirement home because they encourage family members to come live with their elders rather than just leaving them at a retirement home. They also provide 24-hour emergency response and convenient transportation to wherever they need to go. This place is also able to provide affordable living plans, well-balanced meals for seniors, and a safe living environment. The *Dodge Park Rest Home* also has a very high rating when it comes to providing luxury for their residents. This place also provides 24-hour emergency and convenient services. They keep patients busy with daily activities while still making sure they are kept at a healthy pace. This home is known for specializing in taking care of patients with Alzheimer's. This alone shows that the nursing staff is trained to be patient with older patients. This will already be a good candidate for our project because they will want to be involved in trying to better their communication systems.

BrightStar Care of Worcester provides in-home care along with in-home assessments. This means that instead of patients wanting to live on their campus, nurses will come to their house if they don't want to move out of their long-time household. This can be very helpful towards us because it can provide an even larger range of information for our studies. Even though this product isn't being sold to individual homes, this nursing home can help in the long run with eventually trying to provide for individual families. They also take in last minute applicants, allowing more patients in providing better reviews. This fifth nursing home is fluent when it comes to multiple different languages, providing a diverse background. The *Blair House of Worcester* has staff that speaks fluent Greek, Spanish, and Polish. Once again, the diversity of all these languages opens more opportunities for a wide range of patients. They also specialize in working with patients that have dementia... helping us understanding more of what the patients and nurses' communications. However, this place only provides 75 nursing beds... making spacing limited.

The *Beaumont Rehabilitation and Skilled Nursing Center*, as seen in the title, provides more than just a home for elders. They provide care for any injured elders that need to be

nursed back to help along with living services. They are also lenient when it comes to family visiting hours. Unfortunately, the staff is recognized for not having the best timing and patience. If we decide to partner with this nursing home, we'll be able to see the improvements they have made once we provide the smart diaper to them. The humidity detector will be able to quickly able to send a signal to the staff, bettering response time. The staff at *Christopher House* is neat, efficient, and clean. Not only does this home provide nurses, but they have rehabilitation, physicians, dietary professionals, therapists, social workers, and pathologists. This wide range of staff will once again help attract more patients. By already having an organized staff, it will be easy to work with them on any information we may need. Lastly, the *Lutheran Rehabilitation and Skilled Care Center* is seen to have the best review out of the previous seven that were mentioned. This center really cares about feedback that is given. They have a quick response time and take any negative feedback to try and find a solution. This skilled center also provides short-term and long-term accommodations for patients. They also withhold very skilled physical therapists and an understanding staff.

Appendix B: Interview Questions

In order to receive a better understanding of how our product could potentially help nursing homes, we contacted as many nursing homes within the New England area. There were a couple of recorded responses we were able to receive.

Dodge Park Rest Home

Questions	Answer
What products do you currently use to combat patient incontinence?	Brief/diaper pullups
Could these products be improved?	Yes
What percentage of your long-term care residents are incontinent?	
Stress level/ease of management of changing diapers on time (1-10)	5
How many patients do you currently house?	110
What provisions/technology do you have in place to ensure the safe and effective treatment of patients? (Equipment)	Paper task
Do you think this product can help you? Do you think this product would be beneficial to this facility or cause confusion within the staff?	Yes
How likely are you to invest in this product from a scale of 1-10 (10 being the most likely)?	5

Do you think having this device can reduce the number of slip and falls within the building?	No
Have you worked with similar products?	Yes
Would you say the ambient noise is a prominent problem?	Yes
If you could reduce the number of times patients have used the “call” button to contact you, would that have a significant effect on the ambient noise?	No

Christopher House

Questions	Answer
What products do you currently use to combat incontinence and other diaper-related patient issues? How effective are they?	Already have briefs that absorb the moisture and some that absorb for up to ten hours.
Do you think this device could reduce the time a patient remains unchanged?	No. Their patients will press the button or notify them if they feel they need to be changed. They already have a communication system for that.
Due to this, how are the patients affected? (Decubitus ulcerations, etc.)	They aren’t.
Stress level/ease of management of changing diapers on time (1-10)	Certified nursing assistants do the direct care. Stressful because they are all also doing other types of care. During the morning time, getting them awake and ready for breakfast has them more on a busy schedule dealing with the staff’s routine.
How many patients do you currently house?	
What communication devices do you have in place to ensure the safe and effective treatment of patients?	Each room either has a button, pressure pad, or blow tube to alert the nurses’ desk. A control panel with the room number buttons light up so it specifically notifies the staff which room needs assistance.

Do you think this product can help you? Do you think this product would be beneficial to this facility or cause confusion within the staff?	Technology is 23 years old. There is all one system. If patients are aware of their briefs, they press the call button and signal is sent to the nursing desk.
How likely are you to invest in this product from a scale of 1-10 (10 being the most likely)?	Less likely. Only if it is cost effective. Every year, nursing homes in Massachusetts lose money every year.
Have you worked with similar products?	Nothing electronic, just absorption briefs.
Would you say the ambient noise is a prominent problem?	Awful, not welcome or wanted within the technology at all. Could disturb the patients easily. More would prefer if it made noise at the nurses desk. They already have a call system (others have a wetness setting). They don't have independent devices, just all within one system to the desk. Not looking into updating technology.
If you could reduce the number of times patients have used the "call" button to contact you, would that have a significant effect on the ambient noise?	Yes, would want residents (already have residents) who make their needs known. Our sensor would only be beneficial for residents who aren't able to physically ask for help through the button. Other patients just press the call button.