Tyco Nurse Call Pull Station Redesign

Major Qualifying Project Report

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By:

Mariela Qirici

Mark McCabe

In Cooperation with:

Shanghai Jiao Tong University

With Project Partners:

Liu Haoliang & Cao Jiajun

Co-Advisor: Professor Lin Yanping

Approved by:

Advisor: Professor Yiming Rong

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Abstract

This Major Qualifying Project (MQP) involves the mechanical redesign of a nurse call pull station produced by Tyco International Ltd. The nurse call pull station was redesigned in order to improve functionality, to reduce variability in activation forces, to eliminate the ultrasonic welding assembly process, and to reduce of manufacturing cost.
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Introduction

The introduction will cover the overall project description, the objectives, and the expected results for the nurse call pull station project.

Project Description

This project involves the mechanical redesign of a Tyco safety product so to improve its functionality and lower manufacturing cost. The specific product is a Nurse Call Pull Station used in hospital rooms and bathrooms giving patients the ability to call a nurse in times of need with the pull of a string. The Nurse Call Pull Station (NCPS) consists of three major mechanical components (Fig.1): the main frame, the Actuator (red) and the Retainer which is ultrasonically welded to the main frame to hold the Actuator in place.

When the pull station is at rest the actuator stays in the upward position (Fig.2). Once the string is pulled the actuator slides down which activates the call. Within the actuator there is a small magnet whose magnetic field activates a Reed switch that is located on the bottom part of a circuit board that snaps in the back of the main frame (Fig.3).

Figure 1 – NCPS Assembly

Figure 2- Actuator in Resting Position

Figure 3- Call Activated
**Specific Problem**

The current manufacturing process and design of the pull station has some flaws because the quality of the manufactured products is not consistent. In order to activate the call a patient needs to pull the string which brings the actuator down and in some pull station it requires a large amount of force to pull it, while in other pull stations the force applied by the patients manages to break the pull station apart. Such excessive variability in activation forces which has caused some hospital patients difficulty in activate a call for assistance.

In order to solve this problem and improve functionality of all manufactured nurse call pull stations it is necessary to determine the sources of the problem. Redesign by focusing on those sources and keeping as many original components of the design in order to reduce cost.

**Objectives**

There are several major objectives that must be accomplished with the new design of the nurse call pull station. The first of these objectives is that the new pull station must have improved functionality. In order to accomplish this objective the new design must have reduced variability in activation forces. Having reduced variability in activation forces will provide the patients needing to use the pull station with more reliability in the case of an emergency.

The second major objective in the design process is that the new pull station must avoid the use of ultrasonic welding in the assembly process. Ultrasonic welding was determined by Tyco to be the main reason for the unreliability of the previous nurse call pull station designs, therefore a new form of assembly must be determined.

The third main objective for the design process of the new pull station is that the manufacturing cost of the pull station must be either reduced or at least maintained from the original pull station design. The original pull station was manufactured at a cost of $15.3593, therefore the manufacturing cost of the new pull station must be either below or at least equal to $15.3593.
The outmost importance must be given to these three main objectives in order for the nurse call pull station to be considered a success.

**Challenges**

In order to avoid ultrasonic welding a snap fit design is needed for the nurse call pull station. However, this brings forth several challenges that must be addressed. One challenge which must be addressed is that our nurse call pull station design must be able to withstand up to 20 lbs of perpendicular force before the pull station breaks apart. This means that by applying a pull force to the actuator in the perpendicular direction, the pull station must not break when a force of less than or equal to 20 lbs of force is applied.

Another challenge which must be addressed is that the nurse call pull station design must be waterproof as it may be used in a bath or shower and involves electrical parts. Using snap-fits in may complicate the waterproofing process in several ways. One example is that snap-fits are not always airtight and could allow leakage of water. Therefore, snap-fits should always have a layer between them and any electrical components. Having snap-fits which do not bore through the entire pull station may lead to weaker product designs as they will not be able to hold the product together as tightly.

A third challenge which must be addressed with the new design is that the new nurse call pull station design must have a reduced manufacturing cost in comparison with the previous nurse call pull station design. Using snap-fits in the new product design creates an added element which could increase costs of the new designs as larger molds or stronger plastics may be needed. Therefore careful consideration must be taken when creating new designs with the goal of reducing manufacturing costs.

**Expected Results**

By the end of this project the redesigned Nurse Call Pull Stations must have consistency in manufacturing as each and every product will require the same force of activation. In addition, manufacturing costs shall be lowered and the new product must meet both the costumer and manufacturer’s needs.
Background

The background will cover the research done before starting the project. This research includes company research, possible causes of the problems with the pull stations, competitor product research, and technology research relating to the improvement of the pull station products.

Company History

Tyco International Ltd. is one of the largest, most innovative companies today with over 69,000 employees and over 1,000 locations throughout the world. The goal of Tyco is to advance safety and security throughout the world by creating innovative technologies and improving current technologies in both fire protection and security fields.

Tyco was started back in 1960 by Arthur Rosenberg in Waltham, Massachusetts. It was opened as a research laboratory to do experimental work for the government. In 1962 Rosenberg decided to start working on high-tech products to sell commercially. This progress towards more commercial products led to the company going public in 1964. The company then changed its name to Tyco Laboratories, Inc. in 1965. Since then the company has grown to outstanding heights with becoming an over $10 billion dollar business and having over 3 million customers worldwide. George Oliver is the current CEO of Tyco and was also elected to the Board of Directors in 2012. George Oliver also happens to be an alumnus of Worcester Polytechnic Institute and also serves on the Board of Trustees at WPI.

Tyco is currently split up into five main operating groups. These groups include Tyco Fire and Security, Tyco Electronics, Tyco Healthcare, Tyco Engineered Products and Services, and Tyco Plastics and Adhesives. Although, over 80% of total revenues comes from the first three operating groups alone. The nurse call pull station project is being done under control of the Tyco Healthcare operating group.
Causes of the Problem

As mentioned earlier, Ultrasonic Welding is used to weld the retainer on the main frame once the actuator is placed within the grooves of the main frame. Ultrasonic welding is an industrial technique whereby high-frequency ultrasonic acoustic vibrations are locally applied to workpieces being held together under pressure to create a solid-state weld (Fig. 4). (Craftech corp., 2014)

By examining the sample pull stations and speaking to Tyco representatives the two main sources of the problem became apparent. Tyco is not able to control the ultrasonic welding process very well in their manufacturing facilities. When the parts are welded together there are cases in which more plastic then necessary melts from the friction, therefore causing the extra melted plastic to get in the way of the actuator once dried. Because of this extra plastic more force is needed to pull the actuator down. Sometimes the welding process has not melted enough plastic which causes the pull station to break apart when pulled.

Another reason why the pull station does not work well is due to the design of the actuator. Figure 5 displays the actuator on the main frame and outlined in blue is the base of the actuator which helps keep the movement of the actuator parallel to the main frame once the retainer is soldered. This base however does not seem to be large enough to do the job right. When the actuator is pulled by the
string it wiggles non-horizontally between the retainer and main frame as showed by the blue arrow in figure 6. This non-horizontal movement is what creates the marks shown by the red arrows (Fig.6) and which brings forth the need for more force to pull the actuator down since it does not slide freely parallel in between the main frame and retainer. The pull station pictured in figure 5 and 6 also shows that faulty ultrasonic welding might not be the only reason for the stations breaking apart. Extra melted plastic is apparent on the sides yet the retainer has still broken off which means that the station broke due to the force applied to the main frame and retainer by the actuator.

A different sample pictured on figure 7 shows clearly how the actuator causes the retainer to separate from the main frame when pulled. There are two little bumps within the top of the grooves of the main frame which are used to hold the actuator up when not in use. When the actuator is initially in the upward position being pulled the bumps are trying to hold the back (2 legs) of the actuator up while the front is being pulled down by the string. This causes the actuator to not slide down smoothly or parallel to the main frame thus putting force on the retainer and eventually separating it from the main frame.
In order to solve this problem and improve the functionality of all manufactured nurse call pull stations it is necessary to redesign the product with a more functional actuator and an assembly that does not require ultrasonic welding.
Competitor Products

This section gives an overview of two competitor products to the Tyco nurse call pull station that is being redesigned.

Zettler

Zettler was founded in Munich Germany in 1877 as Elektrotechinsche Fabrik Alois Zettler and it quickly became a recognized name for quality fire detection, light call and other building control Solutions. In 1996 Zettler became part of Tyco and has since succeeded in many aspects. (Tyco, 2012)

Zettler has a competing pull station known as the Sentinel Touch Nurse call system which differs from the EZCare Pull station for it features a Toilet Emergency Station (ZTS030510) which is wired to a Shower Emergency Station (ZTS030501). The Toilet Pull Station features a latching call switch with a call assurance LED and a reset button which cancels the call for both the Toilet and Shower Station so the Shower station is a 1-gang station which works only in conjunction with the Toilet station.

The Zettler pull station also includes snap-fits in its design as the plastic faceplate is snap-fit to the plastic frame. Also, internal and external neoprene rubber gaskets are inside the Zettler station in order to prevent excess moisture from accumulating within the pull station. Both of these ideas could also be adopted into the design for the new pull station for Tyco.

TekTone

TekTone has been around since the 1970’s and their production facility specializes in high quality and affordable nurse call, apartment entry, wireless nurse/emergency call, radio pocket paging, area of rescue assistance systems, and alert integration systems that are used in an enormous number of applications. (TekTone)TekTone has a similar product to the EZCare Nurse that works with the Tek-CARE 500 system systems called the SF337C Emergency Station. This pull station is also waterproof and using rubber mounting gaskets and is therefore very similar to the Zettler pull stations.
Technology Research

This section summarizes the groups chosen technology for the nurse call pull station redesign.

Snap-Fit Design

Snap-fit assembly is known in the engineering world for being the simplest, quickest, and most cost-effective way to assemble two parts. Not only does snap-fit design make assembly east but it also provides the possibility of disassembly if needed. The possibility of disassembly can make products both easier to fix and can make products easier to recycle for they can be broken apart more easily. As long as a snap-fit is designed properly not much can go wrong in the production process, therefore it is most beneficial to redesign the nurse call pull station using snap-fit design.

Cantilever snap-fits are the most commonly used snap-fits in engineering design due to their simplistic and effective design. U or L shaped cantilevers may also be used in different scenarios if a product requires tighter packaging. The updated designs for the new nurse call pull station will most likely involve the use of the basic cantilever snap-fits for the U and L shaped cantilevers are not needed in the design of our product.

Any type of thermoplastic is the most recommended material to use for snap-fit design. Thermoplastics are most recommended due to their high flexibility, low coefficient of friction, high elongation, and sufficient strength and rigidity. Therefore, thermoplastics will most likely be used in the design process for the nurse call pull station.

In a snap-fit design there are two angles that must be chosen for optimal performance of the snap-fit. These two angles are the angles of the assembly side and the angle of the retraction side of the snap-fit. The assembly side of the snap-fit is used to simplify the assembly of two parts therefore the smaller the angle of the assembly side, the easier the product is to assemble. The retraction side is used to make disassembly of the product more difficult or even close to impossible based on the intended desire. Therefore, the steeper the retraction side angle the more difficult it is to disassemble the
Another important feature of the snap-fit to consider in the design process is the overhang depth. The overhang depth is the length from the outer tip of the assembly and retraction sides to the base of the assembly and retraction sides.

The two major design considerations for the design of a snap-fit are assembly integrity and the strength or rigidity of the snap-fit beam. Integrity is controlled by both stiffness (k) of the beam and also the amount of deflection required for assembly and disassembly. Integrity may also be increased by increasing overhang depth of the snap-fit although this will also increase beam deflection which will put more stress on the snap-fit beam. Having more stress on the beam could result in failure of the beam if the stress level reaches above the yield strength of the material. Rigidity of the snap-fit can be increased by either using a higher modulus material (E) or by increasing the cross sectional moment of inertia (I) of the beam. Multiplying E*I will determine the total rigidity of the given beam length.
Methodology

The methodology will cover the preliminary testing of the original pull station products as well as the initial brainstorming done in order to create new pull station designs.

Initial Testing

In order to improve the future concept designs of the nurse call pull station the problems of the original design first had to be assessed. The first testing that needed to be accomplished was the testing of the variation in pull forces on the original pull station design. This testing was done using an electronic force meter on five different samples of the original pull station design. Each sample was held vertically in place on a wall and the force meter was attached to the pull string of each sample. The force meter was then pulled until the device was activated, therefore showing the activation strength needed to activate the device. The average activation forces were calculated from each device and the results were calculated as such:

<table>
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<tr>
<th>Sample No.</th>
<th>Activation force (lbf)</th>
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<tr>
<td>#1</td>
<td>1.4</td>
</tr>
<tr>
<td>#2</td>
<td>1.5</td>
</tr>
<tr>
<td>#3</td>
<td>1.5</td>
</tr>
<tr>
<td>#4</td>
<td>2.0</td>
</tr>
<tr>
<td>#5</td>
<td>2.5</td>
</tr>
<tr>
<td>Mean Value</td>
<td>1.8</td>
</tr>
<tr>
<td>Std. Variance</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Although each sample had activation forces which complied with the allowed range of 1-3 pounds, there was quite a large overall variation between the activation forces of the products. Any variations in the products can lead to uncertainty in the reliability of the products and any amount of uncertainty is unacceptable in the medical emergency industry. Therefore, it is important to create a product which is reliable and consistent with minimum variability in its activation forces.
Concept Generation

Clarification of the problem and analyses of the causes were the initial step towards an improved design of the nurse call pull station. With a better understanding of the problem the redesign would be focused on the flaws of the original design so that resources and effort would be used efficiently. The brainstorming process would be open to a wide range of ideas whether feasible or not in order to allow more options for improvement. Initially each group partner generated one redesign concept and then classified the concepts into certain categories so later more ideas could be explored on the specific categories.

Choosing Criteria for Concept Designs

While choosing the criteria for the concept designs it was important to focus attention on many of the problems of the original design while also keeping all the important criteria needed to produce a successful nurse call pull station. The criteria selected were used to judge the initial concept designs to lead to an optimal design choice for the product.

One group of criteria involved the strength of the product design. Strength of the product design is very important as the pull stations will undergo much stress during their lifespans and must be able to withstand these forces. The different strengths analyzed were the strength of the actuator, the product assembly strength, and the endurance strength of the entire product.

Cost was another group of criteria focused on when analyzing the design concepts. The costs analyzed with our concepts involved both material and manufacturing costs. Most of the cost involved with the original design comes from the amount of material needed to create the pull stations. A much smaller amount of cost is needed for manufacturing of the pull stations although both costs are
important in the concept design process as the overall goal is to reduce the overall cost involved with the production of each pull station.

A large amount of criteria was based on problems with the original design of the nurse call pull stations. Two of the problems focused on were the activation force needed to pull down the actuator and the stability of the forces required to pull the actuator down. In the original pull stations the activation forces of the actuators were not stable and some pull stations required much more force to pull the actuator. The goal is to solve these past problems with the new concept designs.

Another problem with the original pull station involved the actuator not staying flat against the surface of the main frame. The problem with the actuator not staying flat is that the retainer had to withstand much force through time as the actuator lifted from the surface of the main frame. The actuator would also create many cuts in the main frame as the actuator tilted and was pulled down when being activated. In the new design concepts it is important to keep the actuator flat against the main frame as to avoid these previous problems.

Ease of assembly for the original pull station was a large problem as the ultrasonic welding process needed to attach the retainer to the main frame was very difficult and unreliable. Creating a new pull station design using a method other than ultrasonic welding was very important and one of the main objectives of the project. Therefore, ease of assembly was another piece of criteria evaluated when producing concept designs and was possibly the most important piece of criteria evaluated.

The final piece of criteria involved the waterproof capabilities of the design concepts. This piece of criteria was easy to judge when coming up with concept designs for a concept would either be waterproof or not. Some of the concepts judged did not seem to be very waterproof but if the other pieces of criteria of the concept were very good the product would still be considered but future adjustments would have to be made to make the concept waterproof. Every final design is required to
be waterproof, therefore concepts that are initially waterproof are more likely to be used for future evaluation.

Assigning Importance to Criteria

Assigning different levels of importance to the different criteria used was very important in the process of choosing a design concept. Assigning different levels of importance was needed, for not all of the criteria used in the concept judging process were equally important to focus on. Therefore, it was important to create an effective method to be able to weigh the different criteria against one another.

To simplify the process of prioritizing certain criteria it was decided to create a matrix in excel to rate the different criteria against one another. This process was first started by entering all of the ten criteria into a matrix in excel. The matrix listed the ten criteria down one column and then had one row that listed the same ten criteria in the same order. Using the matrix it was possible to weigh the different criteria against one another. In order to compare criteria, one of the criteria would be chosen from the top row and a column would be found with a different piece of criteria and the two would be compared. If the two pieces of criteria were equally important a “1” would be placed in the spreadsheet space aligned with the two criteria. If the criteria from the top row was more important than the criteria from the column, then the number would be higher depending on how much more important the criteria from the row was. For example, if the criteria from the top row was twice as important as the criteria from the column then the number “2” would be placed in the space aligning the two criteria. If the criteria from the top row was less important than the criteria from the column, then the number aligned with the two criteria would be less than 1. For example, if the criteria from the column was 4 times as important as the criteria from the top row then the number aligning the two criteria would be “0.25”.
As more numbers are entered into the spreadsheet, the numbers can be used to make associations between the different criteria. In order to show an example of the different associations, three imaginary criteria known as A, B, and C will be used. For example, if criteria A is twice as important as criteria B and it is known that criteria B is twice as important as criteria C, then the association can be made to show that criteria A is four times as important as criteria C. This method is used to simplify the judgment process and to help create a better understanding of the associations between the different criteria for the concept designs.

After one column was completely filled in it was possible to figure out the percentages of importance from each of the different criteria. This was done by adding together one entire column of values and then by dividing the numbers related to the criteria from each row by the sum of all the values. The number given after the calculations was the percentage of importance related to each specific criteria.

Deciding the different weights of the criteria was a very difficult process. It was first decided that the criteria relating to the problems from the original design should be most important to the concept design. Therefore, it was necessary to decide how to compare the other criteria to the more important criteria such as the activation force, stability of the activation force, ease of assembly, and ease of making waterproof. When speaking to Jim Roberts, our sponsor from Tyco, about the list of important criteria he believed that ease of assembly should be the most important of all of the criteria. Therefore the most importance was placed upon the criteria of being easy to assemble.

Material cost, assembly strength, and the product’s endurance were the next most important in the list of criteria. Material cost was important in the concept design for one of the overall goals in this project was to reduce the overall cost of the nurse call pull station product and most of the cost comes from the cost of material. Assembly strength and endurance were also very important pieces of criteria.
to consider for although they were not the largest problems with the old design, they were still
problems that existed and needed to be improved.

The piece of criteria that ranked next in level of importance was the criteria on how flat the
actuator remains. This piece of criteria was important for on the original design the actuator had trouble
staying flat. Therefore, the actuator would lift and cut into the main frame thus creating grooves and
cuts in the plastic. This was also dangerous for when the actuator would lift it would apply force to the
retainer and could lead to eventual failure of the product.

The pieces of criteria that ranked last on the list of importance were the manufacturing cost and
the strength of the actuator. Manufacturing cost ranked low in importance for an extremely small
portion of the cost of the product comes from the manufacturing process. The majority of the cost
comes from the material costs. Strength of the actuator ranked low in importance for the actuator’s
strength was never a problem in the original design of the pull station.

The percentages of importance for our criteria were as follows:

15% - Ease of assembly
13% each - Activation force required, stability of activation force, and ease of making waterproof
10% each - Material cost and assembly strength
8% - Ability of actuator to stay flat
5% each - Manufacturing cost and actuator strength

**Brainstorming Concepts**

After coming up with the different criteria and their weights it was necessary to start
brainstorming different concept design choices. The brainstorming was started by creating a list of all
the possible different features and design choices that could be incorporated into our designs. The list of
ideas was not a final list that could not be added to, for there were other possibilities that may not have come up while brainstorming, but the list was a good way to initiate creativity. In fact, most of the later ideas did not even relate to a lot of the different categories on the brainstormed list as new ideas were created based on improving earlier design ideas. The list made it possible to brainstorm 6 different categories of design ideas. These 6 categories included assembly method, actuator locking design, actuator groove design, snap-fit locations, snap-fit styles, and the actuator leg design.

The list of initially brainstormed categories was as follows:

- **Assembly Method**
  - Retainer snaps on front
  - No retainer (back piece snaps on)

- **Actuator Locking Design**
  - Peaks (fixed through sides)
  - Hooks (fixed through top)

- **Actuator Groove Design**
  - Straight grooves
  - Tapered grooves

- **Snap-fit Locations**
  - Side snap-fits
  - Vertical snap-fits

- **Snap-fit Styles**
  - Standard
  - U-shaped
  - L-shaped
  - "Round or Special" snap-fits

- **Actuator Leg Design**
  - Straight
  - Hooked
  - Looped
Results
The results section covers the new nurse call pull station concept designs and the cost calculations associated with the final concept designs.

Initial Concept Drawings

After brainstorming lists of criteria and guidelines for the concept designs it was possible to begin brainstorming different concept ideas. Four different initial concept ideas were created when doing the initial brainstorming. Then each concept was analyzed in order to find out which concept designs should be continued and which aspects of each design were the strongest.

Shown below is the drawing for initial concept #1:

The first design concept used an over the top assembly method with the actuator sliding in from the top and with the retainer then snapping into the top. The actuator had a small bump on its top which snapped into a hook on the retainer in order to be held in place.

There were many pros to the initial concept design #1. One pro was that the actuator was held very securely in place due to the track and walls which held it into place. Concept design #1 also seemed...
to require low activation forces to pull the actuator down. The concept also did not require any ultrasonic welding in its’ production process.

The two cons to this design were that the design may not have been fully waterproof and that the cost could have been high due to produce due to the complexity of the design.

Shown below is the drawing for initial concept #2:

![Figure 9 – Concept 2](image)

Concept #2 used a similar design style to concept #1 as it used an over the top assembly method. The differences between concepts #1 and #2 were that the actuator legs in #2 hooked around and the grooves that the actuator slid down were tapered as well. These differences allowed the actuator to stay securely in place during use instead of wiggling insecurely.

There were also many pros to the design of concept #2. One pro was that the actuator was very secure. Also, the concept seemed to be waterproof and it avoided ultrasonic welding.

Some cons of the concept were that the activation forces could be high with so many devices being used to keep the actuator from wiggling and also that the production costs could be expensive on concept #2 as well.
Shown below is the drawing for initial concept #3:

Figure 10 – Concept 3

Concept #3 also used an over the top assembly method. This concept also used the tapered grooves for the actuator such as the ones used in concept #2. The actuator was held up in place by the legs using the same design method as the original product.

One of the pros of concept #3 is that the actuator is held securely in place due to the use of the tapered grooves. Also, ultrasonic welding is used to assemble the product.

One of the cons is that the activation forces will be similar to the original product for the same activation method is used using the legs of the actuator to clip into place. Concept #3 also may not be waterproof as the snap holes would have to be cut through the entire back of the device which may allow water to leak through. Once again this concept may also be costly due to the higher complexity of its design.

Shown below is the drawing for initial concept #4:
Concept #4 is different from the other three initial concept designs as it uses an over the front assembly method instead of an over the top assembly method. In this design the retainer snaps into place over the whole front of the pull station and clamps the actuator into place. The actuator is held by hooks on the main frame which grab onto a bump placed at the top of the actuator.

There are several pros to concept #4. The actuator would most likely be held securely into place and would have a larger base to avoid any wiggling. The activation force would most likely be low due to the flexibility of the hooks. The snap-fits would be durable especially after the whole product is screwed into place. Also, concept #4, just as the concepts before, did not use ultrasonic welding.

The biggest con for this design was the fear that it would not be waterproof as the four snap-fit holes could allow water to flow through. Also, once again this concept design could be very costly as it is more complex than the original design.
Judging the Initial Concepts

When judging the four initial concepts the criteria decided on previously was used to analyze all of the different aspects of the designs. Each piece of criteria was judged on a scale from 1 through 5. To start the grading process the original design of the pull station was assigned a 3 for all of the criteria. Next the new concepts were graded by giving each concept a 4 or 5 for a certain piece of criteria if that piece of criteria was better than the original design. If the criteria for the concept was worse than the original design then the concept would receive a 1 or a 2. If the concept had the same capabilities as one piece of criteria for the original design then it would be given a 3. After grading all of the criteria, the weight percentage of each piece of criteria was multiplied by the grade the concept had received. Next all of the values from the product of the percentages and ratings were added together to provide an overall grade for each concept. The final grade determined the concepts that were the best and which concepts were not good choices to continue working on. The scoring also made it possible to take aspects from concepts that scored higher in different criteria fields and to combine them in order to create a better concept.
Final Designs’ Development

To develop the final concepts, the group optimized and combined different aspects from the initial drawings. One preferred idea between group members was that involving a full front retainer similar to initial concept 4 (Fig.11). In order make this design a final one, problems such as waterproofing and cost needed to be addressed, and a lot of optimization needed to be done. The snap fits of Concept 4 (Fig.12) were complex and holes on the main frame very large, which would cause both increase in price and water leakage into the circuit. By adopting simple snap fits as in concept 1, making those snap fits point outward from the main frame towards the front of the pull station, with the snap fit holes on the full front retainer, the cost would be reduced and the holes for the snap fits wouldn’t go through the back. This simple modification addressed two major problems with concept 4 making it one the best redesign options thus far. The optimized snaps are shown in Fig.13 pointing out of the main frame and the snap fit holes are on the full front retainer shown on Fig.14.

To simplify the design, uniform cross section snap fits where chosen to be used for this design. The dimensions of each snap were calculated to make sure the snaps properly mated without breaking. The Snap Fit Design Manual was used as reference for formulas to make sure the deflection was optimized with respect to yield strain of the material, in this case Cycoloy. (BASF, 2007)
Based on calculations and testing, the snap fits designed didn’t meet one of the criteria that the pull station must withstand a 20lb perpendicular pulling force without breaking apart or disassembling which is why the design was optimized to utilize the mounting screws for two purposes. The holes on the full front retainer where the mounting screws are inserted are designed to allow the mounting screws not only to affix the main frame to the wall but to hold the retainer and main frame together.

Figure 15 shows the back of the full front retainer (final design). The pockets for the screws come out the back of the retainer and slide within the screw holes of the main frame.

The full front retainer, supported by both the snap fits and the mounting screws also contributes to keeping the actuator from wiggling. Given that the retainer will be stable, the actuator will not have room to wiggle (See Fig 7- Causes of the Problem), it will move parallel to its track and allowing for the applied force to be exerted toward activation. Prototypes were made with the redesigned retainer and main frame snaps, however the actuator was not redesigned to test whether the modifications thus far would fix the problems. The 3D drawing of this prototype is shown in figure 16 and testing proved that
the actuator definitely needed redesign. Even though the separation of the retainer from the main frame was not a problem anymore, the bumps that hold the actuator in resting position held the legs up while the front of the actuator was being pulled down by the string. This caused the actuator not to slide down smoothly parallel to its track which meant all the force that was being applied for activation didn’t go directly to get the legs over the bump but also was applied to the main frame and retainer as in the original design.

In order to assure improved functionality for the final concept the actuator was redesigned. The base of the actuator was made bigger and the legs of the actuator aligned in the same direction that the activation force would be applied to avoid wiggling.
By making the actuator legs be closer to the parallel plane which the activation force is applied, more of the force is exerted towards activation assuring improved functionality. Figure 18 shows how the vertical legs are closer to the plane where force is exerted for activation compared to the perpendicular legs of the original design (\(dY_{\text{original}} = 0.68\text{in}, dY_{\text{redesign}} = 0.46\text{in}\)).

The final main frame was optimized from the design that the first prototype (Fig 16) in order to be more cost efficient (reduction in material) and compatible with the redesigned actuator. The bumps that hold the actuator in the upward position were placed further away from the actuator track facing in the tracks direction in order to mate with the new actuator leg bumps that now face outward (Fig 13 & 15). The figure below shows the final redesigned actuator and the main frame track compatible with this actuator is pictured in figure 19.

Testing of prototypes of the final design proved that the vertical actuator legs addressed the wiggling problem and allowed for the actuator to slide smoothly on the track thus giving this design great potential to be one of the chosen designs by Tyco.
From the first round of concept selection, Concept 1 achieved the highest score when graded based on chosen criteria thus the group decided to optimize the design and provide more redesign options. After communicating the concept idea to the Tyco sponsor, the group took the feedback given and put together a rough 3D model (Fig.20). Instead of having an overhang, the retainer was designed to be more arched than the main frame, leaving space for the actuator legs to slide in and clip on two bumps located on the interior of the front retainer wall. The actuator legs were redesigned to face vertically (on a parallel plane to that which the activation force is exerted) rather than horizontally (perpendicular to the activation force).

This design was then optimized to address water proofing issues that came with the large snaps of the retainer penetrating through the main frames. The retainer could be supported by the mounting screw thus eliminating the need for large more secure snaps and allowing for simpler snaps to be placed on its sides.
This concept was further optimized to address possible assembly weaknesses and aesthetical preferences specified by Tyco. The side snaps got redesigned to be concealed thus facing the interior of the assembly. Given that the retainer could be supported by the mounting screw, the top two side snaps were eliminated and replaced by guiding bumps. The main frame was also redesigned (Fig.22) to be compatible with the retainer (Fig.23 & Fig.24).

The vertical actuator legs for this design (Fig.20) would be visible through the main frame opening when activating a call which would be aesthetically unpleasing. For that reason the group decided to go back to the original actuator redesign of Concept 1 and replaced the bump on the retainer with hopefully more flexible strip (Fig.24).
As mentioned earlier prototypes were made during the design process (Fig.25). The prototypes of this design were made without the supporting plastic by the mounting screw on the retainer. Testing proved that the retainer and retainer flexible strip which holds the actuator in place lacked in flexibility thus causing the need for higher activation force.

The prototypes (Fig.26), which were made of Nylon, broke while testing confirming that this design would not withstand the required life cycle.

Although the prototypes broke, the addition of supporting material by the mounting screw would add durability. With some more optimization such as, switching the design of the actuator to that shown in Figure 2 would lower the force needed for activation making this another great option.
Cost Evaluation

Analysis of the cost of the original Nurse Call Pull Station design was necessary before doing the cost calculations for the redesign concepts. In the redesign of the nurse call pull station only the actuator, main frame, retainer and ball were changed, thus to make sure the new design fell within or below budget, only the cost of these parts needed to be calculated and compared to the cost of the same parts in the existing design. Parts which were redesigned due to functionality problems were the shower station main frame, the actuator and the retainer. The ball was redesigned because based on our observations of the product cost list and advice from Jim Roberts, the extremely high cost of just one plastic ball compared to the other parts seemed like the perfect opportunity to save on cost. The initial approach to cost analysis was through calculation of product cost per volume given that the cost of each part was known from the product cost list (Fig.26) and volume could be found from the 3-D models of the original design provided by Tyco which are shown in the table below.

<table>
<thead>
<tr>
<th>Volume of Parts (in³)</th>
<th>Actuator</th>
<th>Main Frame (Shower Station)</th>
<th>Retainer</th>
<th>Ball</th>
<th>Ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>(JJ) Top Retainer</td>
<td>0.207581</td>
<td>2.2869</td>
<td>0.282623</td>
<td>0.9241</td>
<td>0.116</td>
</tr>
<tr>
<td>(HL) Full Front Retainer</td>
<td>0.2227154</td>
<td>1.2861</td>
<td>1.1633</td>
<td>0.9241</td>
<td>0.116</td>
</tr>
<tr>
<td>Existing Design</td>
<td>0.173597</td>
<td>2.0417</td>
<td>0.114449</td>
<td>0.9241</td>
<td>N/A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Prod Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shower Station</td>
<td>0.6500</td>
</tr>
<tr>
<td>Actuator Red</td>
<td>0.3050</td>
</tr>
<tr>
<td>Retainer</td>
<td>0.1430</td>
</tr>
<tr>
<td>Ball Plastic</td>
<td>2.9200</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Initial Cost Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.S. Cost</td>
<td>$ \frac{0.65}{2.0417} \text{ in}^3 = 0.32 \frac{$}{\text{ in}^3}</td>
</tr>
<tr>
<td>Actuator Cost</td>
<td>$ \frac{0.305}{0.1736} \text{ in}^3 = 1.76 \frac{$}{\text{ in}^3}</td>
</tr>
<tr>
<td>Retainer Cost</td>
<td>$ \frac{0.143}{0.1144} \text{ in}^3 = 1.25 \frac{$}{\text{ in}^3}</td>
</tr>
<tr>
<td>Prod. Cost</td>
<td>$ \frac{2.92}{0.9241} \text{ in}^3 = 3.16 \frac{$}{\text{ in}^3}</td>
</tr>
</tbody>
</table>

Figure 27 – Product Cost
These calculations proved to be inaccurate due to the large difference in cost per volume material between the shower station and retainer even though they are both made of the same material called cycoloy.

Besides the material cost, product cost varies based on manufacturing process and product criteria. The production of each part of the nurse call pull station is done through injection molding. The thermoplastic material, in this case acetal or cycoloy, is melted and then injected within the mold which has either one or more cavities shaped as the desired part. Once the material is forced within the mold it is cooled and later taken out of the cavity. This manufacturing process is important in determining the cost of the parts because the cost of the part depends mainly on machining time per piece by each mold which can be reduced by the use of multi-cavity molds. As indicated by Jim Roberts, in the existing design the main housing (shower station) is made in a 2 cavity mold while the smaller parts (actuator, retainer, and ball) are made in 4 cavity molds. A way to reduce cost would be by adding more cavities however that is not realistic for 2 and 4 cavities are sufficient. Given that the number of cavities per mold used to make the existing design is sufficient, the assumption that the manufacturing process for the redesigned parts will be the same as the existing is made therefore allowing for an online cost estimator to be used. With process parameters remaining the same, part information can be entered in the online estimator for the existing design giving a cost estimate (which hopefully is consistent with the real cost), then the equivalent redesigned part’s information can be entered in the estimator and the results can be compared.

For this analysis the Costumpart.net Inaction Molding Cost estimator was used. (Costum Part, 2014). To make sure the estimator worked well the existing designs parts criteria were entered and the estimator’s results were compared to the actual product cost and are shown in the Table below. (For details on part information and calculations see Appendix (A).
Existing Design | Estimated Cost ($) | Real Cost ($)  
---|---|---
Actuator | 0.305 | 0.305  
Main Frame | 0.882 | 0.65  
Retainer | 0.443 | 0.143  
Ball (2) | Assume 2.92 | 2.92  
Total (without ball) | 1.63 | 1.098  
Total (with ball) | 7.47 | 6.938  

The Estimator was right on point when calculating the actuator cost although it was not so precise for the Main frame and Retainer. It was assumed to work well enough since estimates from a molder won’t be 100% accurate as they do not know the real cycle time and efficiency and scrap rate until they have a mold running. Due to missing information for the ball material, it was assumed that the estimator was right on point when the ball cost calculation was made. After discussion with Jim the high cost of the existing ball was assumed to be due to expensive material which if switched to cycloy in the redesign should bring forth significant savings. Estimates of the redesigned parts were generated by keeping process parameters the same as in the original design and the results are shown in the following table.

**Comparison of Product Cost According to Estimation from Online Estimator**

<table>
<thead>
<tr>
<th></th>
<th>Existing Design</th>
<th>Full Front Retainer</th>
<th>Top Retainer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actuator</td>
<td>0.305</td>
<td>0.325</td>
<td>0.285</td>
</tr>
<tr>
<td>Main Frame</td>
<td>0.882</td>
<td>0.720</td>
<td>0.876</td>
</tr>
<tr>
<td>Retainer</td>
<td>0.443</td>
<td>0.925</td>
<td>0.566</td>
</tr>
<tr>
<td>Ball (2)</td>
<td>2.92</td>
<td>0.752</td>
<td>0.752</td>
</tr>
<tr>
<td>Total (without ball)</td>
<td>1.63</td>
<td>1.97</td>
<td>1.727</td>
</tr>
<tr>
<td>Total (with ball)</td>
<td>7.47</td>
<td>3.474</td>
<td>3.231</td>
</tr>
<tr>
<td>Total Cost</td>
<td>15.3593</td>
<td>11.3633</td>
<td>11.1203</td>
</tr>
</tbody>
</table>

Based on this estimate the top retainer design proves to be more cost efficient at $11.1/NCPS compared to the full front retainer design at $11.4/NCPS
Summary and Conclusion

The nurse call pull station project was a challenging yet an excellent experience. The group was able to develop two different successful final concept designs. The full front retainer design and the top retainer design. The full front retainer design proved to be the more reliable and preferred over the top retainer design since it achieved all the objectives, including improved functionality, reduced variability in activation forces, elimination of the ultrasonic welding process, and reduction of manufacturing cost. The cost of this design is estimated to be slightly higher.

The top retainer design should address all the required specifications and achieve all objectives given the adjustments mentioned in the results section are taken into consideration. Although the prototypes could not withstand certain forces and were not very strong, this may have been due to the material with which the prototypes were formed. With the right materials the concepts shall prove to be much stronger products.

As with any project there are always several recommendations in order to continue or improve upon the completed project. With both of the completed design concepts there is further optimization that could be added following analysis of the concepts in order to improve them. The prototype design process also could have been improved to make stronger prototypes which could allow official testing. It also may be possible to run strength tests on the 3D models of the prototypes by using certain computer programs. More research could be done into using these programs in order to simplify the testing process.

Throughout this project the group gained a lot of experience in the mechanical design field and were extremely grateful to be given the opportunity to work on such a project. The group hopes that Tyco will be able to implement the new designs into their future pull station designs and would like to thank anyone who helped them throughout the entirety of the project.
References


http://www.craftechcorp.com/ultrasonic-welding/

http://science.howstuffworks.com/ultrasonic-welding2.htm


Appendix A - Calculations

<table>
<thead>
<tr>
<th>Part &gt;</th>
<th>Actuator</th>
<th>Main Frame</th>
<th>Retainer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NCPS Design &gt;</td>
<td>Existing Design</td>
<td>(JJ) Top Retainer</td>
</tr>
<tr>
<td>Max Wall Thickness (in)</td>
<td>Original</td>
<td>JJ</td>
<td>HL</td>
</tr>
<tr>
<td>Projected Area (in²)</td>
<td>0.11</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>Projected Holes SA (in²)</td>
<td>0.013</td>
<td>0.013</td>
<td>0.013</td>
</tr>
<tr>
<td>Volume (in³)</td>
<td>0.174</td>
<td>0.207</td>
<td>0.227</td>
</tr>
</tbody>
</table>

**Projected Area Note:**

(HL) Full Front Retainer = the projected area of the Main Frame and Retainer is on the x-z plane

Existing Design = the projected area of the Main Frame is on the x-z axis

**Part Information Used for Cost Estimation (Same For all 3 Designs)**

Quantity: 100000

Actuator Material: Acetal = Acetal Copolymer, Unreinforced

Main Frame, Retainer & Redesigned Ball Material: Cycoloy = Polycarbonate/ABS Alloy, Unreinforced

Tolerance (in): Moderate precision (<=0.01)

Surface roughness (µin): Normal Polish (Ra<= 16)

Complexity: Simple
**Projected Holes Surface Area Calculations:**

Actuators (all) = 0.013 in²

Main Frame (all) = (2 holes) * (0.02 in²/hole) + (.028 in²) = 0.068 in²

Existing Retainer = 1.69 in * 1.18 in = 1.994 in²

JJ Retainer = (2 holes) * (0.02 in²/hole) = 0.04 in²

HL Retainer = (2 holes) * (0.02 in²/hole) + (1.19 in * 1.93 in) = 2.337 in²

**Ball Part Information Calculations:**

Ball Volume = 0.9241 m³

(We are assuming there is no hole in Ball for simplicity of calculations to obtain the parts maximum dimensions however a projected hole will be taken in consideration when estimating cost)

\[ V = \frac{4}{3} \pi r^3 \]

\[ r = \sqrt[3]{\frac{3}{4\pi} V} = \sqrt[3]{\frac{3}{4\pi} 0.9241 \text{ in}^3} = 0.60424 \text{ in} \]

Ball Diameter = 1.209 in

For Ball Cost Calculations for the new designs Cycoloy will be used instead of the existing material.

Envelope X-Y-Z (in) = (1.208, 1.208, 1.208)

Projection Hole Area = (Circumference of hole at the bottom of Main frame where cord goes in )² / 4(\pi) = 0.0127 in²