Final Design Report: Reflective Coating Process and Cell Design

MECH 4860 – Engineering Design

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Acknowledgements

M2D2 Consulting Group would like to take this opportunity to thank Noel Mattson for the opportunity to work on such an exiting project. Dr Olanrewaju Ojo and Dr Paul Labossiere deserve special acknowledgement for their advice, guidance, and direction during this project. We'd also like to express our gratitude for Dr Raghavan Jayaraman's advice on physical testing procedures, and Dr Arkady Major's assistance regarding the reflectivity test apparatus. Rob Stewart deserves special thanks, allowing us open access to his workshop, in which we built all experimental testing apparatus. We'd also like to thank Aidan Topping for her effort in reviewing all of our reports.

Without the aid of those listed above, this project could not have achieved what it has. Thank you very much.

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2 December 2013

Dr. Paul E. Labossiere, P. Eng.
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Dear Dr. Labossiere:

On behalf of M2D2 Consulting Croup, I am pleased to present you with our Final Design Report, 'Reflective Coating Process and Cell Design'. The report focuses on the development of testing methods and procedures, the implementation and results of the tests, and recommendations for application cells for select coating materials.

On December 2nd, 2013, M2D2 successfully completed the Reflective Coating Process and Cell Design project. Reflectivity and durability testing methods and procedures were successfully developed and implemented in the coating material selection process. Through the use of the reflectivity and durability tests during the design selection process, a new, alternative, cane coating material was found to replace the 3M white reflective tape currently used at AmbuTech.

Should you have any question or concerns, please contact me at DuncanMFStewart@gmail.com or (204) 770 5196.

Sincerely,

Duncan Stewart

Executive Summary

AmbuTech, Inc. is a Winnipeg based company that produces high-quality mobility products for the blind and visually impaired. The mobility canes currently produced are wrapped in 3M white reflective tape, which acts as a reflective coating for the cane. The 3M tape is extremely susceptible to abrasion, and canes lifetimes can be as short as two months because of the deterioration of the reflective tape. M2D2 Consulting Group has been tasked with designing a new reflective coating to replace the 3M white reflective tape, and developing reflectivity and durability testing methods and procedures that would be used on various cane coating materials. M2D2 is also responsible for recommending a final application process and cell for the new alternative cane coating or coatings.

The testing methods and procedures were developed before the selection of the cane coating, as there were no test methods in place to determine a material's reflectivity or durability prior to the start of this project. The reflectivity test used a photocell 'eye', which we can use to determine the amount of light hitting the 'eye'. By shining a light on a test sample, we determined the reflectivity of the test sample. The durability test used the reflectivity test to describe a material's durability in terms of loss of reflectivity. Once the initial reflectivity of a material was determined, the sample was abraded for a set amount of time, and then the sample's newly abraded reflectivity was found. The percent difference between to two reflectivity values described how durable the material was.

The reflectivity and durability tests were then used to determine the reflectivity and durability of the 3M white reflective tape, which we used as the baseline material. We then compared the 3M tape to seven other design materials: mirror film, shrink-wrap over 3M white tape, reflective aerosol spray (Sphere Brite) on white paint, airport quality glass beads on white paint, standard highway glass beads on white paint, powdered glass beads on white paint, and a cage over 3M white tape. The design materials were evaluated based on their weight, reflectivity, durability, and cost. During the screening and selection process, the reflectivity and durability tests we developed were instrumental in selecting the best design material.

We determined that the best design material was the mirror film, as the film was lighter, more reflective, more durable, and less expensive than the 3M reflective tape. A ½-inch diameter, 52-inch long aluminum cane, coated in mirror film, was 3.58% lighter, and

$0.927 cheaper, than a similarly sized cane coated with the 3M white reflective tape. The mirror film also proved to be 16.05% more reflective, and 2.53% more durable than the 3M white reflective tape. Other design materials that also outperformed the 3M tape were the reflective aerosol spray on white paint, powdered glass beads on white paint, and standard highway glass beads on white paint. Although these design materials scored better than the 3M reflective tape, and are therefore valid designs, they did not score as well as the mirror film.

For an application process and cell, we recommend applying the mirror film manually, in a similar fashion currently used to apply the 3M tape. However, a bonding agent should be used to provide a stronger adhesive bond between the cane shaft and the mirror film, to prevent the mirror film from peeling off of the cane. Camie 373 performance adhesive is recommended for its suitability for a wide range of applications, and quick drying time.

We have developed and implemented reflectivity and durability tests, designed a new cane coating to replace the 3M white reflective tape, and provided an application process and cell recommendation for the mirror film, and three other valid design materials. By completing these tasks, we have met the project objective as outlined, and have declared the Reflective Coating Process and Cell Design project a success. Our final coating material selections, as well as our application process and cell recommendations, are detailed in this report. We have also provided and detailed our testing methods and procedures, should any continued research and testing wish to be carried out at AmbuTech.

1 Introduction

AmbuTech, Inc. is a Winnipeg-based producer and distributer of mobility products for the blind and visually impaired. 3M white reflective tape is currently being used as the reflective safety coating on canes, but the tape is susceptible to abrasion, and is scraped off the cane easily. A new, alternative coating needs to be developed that is more durable, lightweight, low cost, and at least as reflective as the 3M white tape. M2D2 Consulting Group has been tasked with developing reflectivity and durability testing methods and procedures, designing a new cane coating that would replace the 3M white tape, and providing a recommendation as to the application cell for the designed coating. The new can coating must be resistant to abrasion and weathering effects, be functional within temperatures ranging from -40°C to 50°C, and cannot be independently light generating.

1.1 Client Background

AmbuTech, Inc., located in Winnipeg, Manitoba, is a leading manufacturer of mobility products for the visually impaired, producing approximately 75 000 canes yearly. The current canes are constructed from aluminum, fiberglass, or carbon fiber shafts to accommodate a customer's budget and personal preferences. 3M white reflective tape is currently used as a reflective coating to help alert drivers the cane user's presence. However, the 3M tape has poor durability, and is particularly susceptible to abrasion. The abrasion will cause segments of the cane to peel or scrape off of the cane, reducing the overall reflectivity of the cane, and compromising the safety of the cane user.

1.2 Client Needs

During the initial visit to AmbuTech, many different design requirements were specified for the project. The new cane coating had to be a white or metallic colour, and the colour has to be consistent throughout the entire coating. Durability and longevity was also a major concern, as the new cane coating also had to be durable enough to resist abrasion and scraping. Because the canes are used both indoors and outdoors, the new coating could not be affected by temperature changes and thermal shock (i.e., a cane user in Winnipeg goes outside in February), and had to resist the effects of humidity and weathering. The reflectivity of the new cane coating needed to have equivalent, or higher, reflectivity than the 3M white reflective tape that was currently used as the cane coating. Finally, the cane coating had to be lightweight and ergonomic to handle, and could not cause health concerns to the end user, through exposure of harmful chemicals, for example.

Reflectivity and durability testing standards and procedures also had to be developed, as there were no test methods in place to evaluate the reflectivity or durability of a potential coating material. The test methods were used to determine the reflectivity and durability of the 3M white tape, as well as the material designs we conceived. The tests were also required, should any testing and research be undertaken at AmbuTech in the future.

Any cane coating application process had to be safe for AmbuTech employees. Personal protection equipment, and an extraction or ventilation unit, in the case of a chemical fumes present during the application process, had to be implemented in order to protect employees. The cane application cell also had to be easily integrated into the AmbuTech manufacturing line, while minimizing impact to current production times.

1.3 Project Objectives

The objectives of this project was to develop reflectivity and durability testing methods and procedures, generate a new, reflective, cane coating, and recommend an application cell and application method for the proposed reflective coating. The testing methods and procedures had to accurately and reliably determine the reflectivity and durability of the test material. Since no test methods, or reflectivity and durability metrics existed prior to this project, the testing methods and procedures are critical to any future research and testing at AmbuTech.

The end cane coating had to be more durable, less expensive, and easier to apply, with equivalent or superior reflectivity. The current average lifespan of a cane varies from two months to a year, and with cane prices ranging from $20 to

$75, replacing canes on a two-month cycle can be extremely expensive for the end user.

The application cell and application process should not expose employees to any materials that could cause health issues, as executives at AmbuTech hold themselves to very high standards for their employee's safety. Should a solvent-based coating be instrumented, safety equipment and an extraction or ventilation system would have to be implemented. The application process should also minimize any impact to production times. Currently, production times are approximately 200 seconds per cane, with tape application times close to a minute. Increasing the production time of applying the coating would greatly impact AmbuTech's ability to produce and ship 75 000 canes yearly. Finally, the acquisition and installation of any new application cell apparatus or equipment should cost less than $200 000.

1.4 Constraints & Limitations

Although the project was left fairly open, there were aspects of the design that were restricted by the client. The cane coating has to be able to operate in temperatures ranging from -40°C to 50°C, and cannot be independently light generating, as an independently light generating cane could draw unwanted attention to the cane user. Also, the overall cane weight with the new coating cannot exceed 10% of the overall cane weight with the current 3M reflective tape, to minimize user fatigue.

Any changes to the current application cell, or any new application cell, cannot interfere with any neighboring cells, or any other production within the manufacturing space. The application cell cannot impact walking paths, as this would impact productivity, and more importantly, safety. Finally, the total allowable budget for the application cell, and any additional auxiliary equipment or machinery required cannot cost more that $200 000.

2 Testing Methods & Procedures

Two tests were developed in order to obtain material data: a reflectivity test, and a durability test. The development of these testing methods and procedures was an integral part of this project as the tests enabled us to determine the durability and reflectivity of the current reflective tapes, along with other reflective materials being considered as coating alternatives. Without these tests, we could not have determined how reflective or durable a material was. The testing methods and procedures were instrumental in obtaining data for the various cane coating materials. The development of the reflectivity and durability tests are each detailed, in turn, from the initial designs, to the construction of test apparatuses, to the final testing methods and testing procedures.

2.1 Reflectivity Testing Methods & Procedures

The reflectivity test was the first test developed of the two tests. Initially, sketches and concept designs were created. These sketches were used to help clarify the reflectivity test objectives; specifically, what kind of environment we wanted to simulate with the test, and the type of data the test would provide. Once the test concepts were finalized, testing apparatuses were devised and created. After the test apparatuses were built, testing procedures were developed that specified operational stages during testing.

2.1.1 Development of the Reflectivity Test & Apparatus Construction

In order to determine the reflectivity of a material, a controlled test procedure had to be developed to obtain useful data. The test was designed to simulate a retro reflective environment (such as light from a car's headlight reflecting back to the driver), while being controlled and accurate.

The first step of developing such a test was obtaining equipment that could sense changes in light levels. The PDV-P5002 CdS Photoconductive Photocell from Advanced Photonix, Inc. was chosen for two main reasons. The PDV-P5002 photocell acted as a light dependent resistor, so taking measurements of different light levels was simple and straightforward, as we could read the cell resistance using an ohmmeter. A graph of cell resistance vs. illuminance of the photocell

(Figure 1) was provided on the PDV-P5002 datasheet (Appendix A). By using PlotDigitizer [**1**], a freeware plot digitizer, we were able to determine the values of two points on the graph (Appendix B), and calculate the equation of the resistance vs. illuminance line provided on the datasheet.

Figure 1: PDV-P5002 cell resistance vs. illuminance plot

For test purposes, nine PDV-P5002 photocells were connected in series to create a cell bank (Figure 2). By combining nine photocells, a larger 'eye' was created for the light to shine onto. Connecting the photocells in series also meant the end reading of the cell bank's resistance would be an average reading of the light detected by the photocells, thereby desensitizing the test to errors caused by variations in light levels.

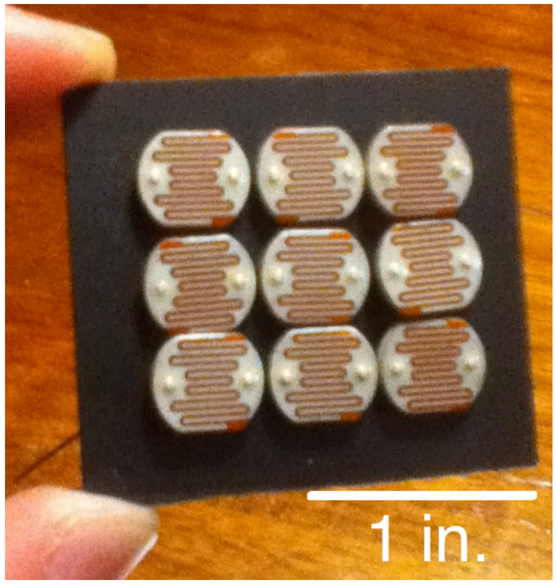

Figure 2: Photocell bank constructed from nine PDV-P5002 photocells

Before proceeding with material testing, we first had to determine the baseline light level of the flashlight. To do so, a long tube was created that acted as a fixture for the flashlight and cell bank, while controlling the distance at which the flashlight was held from the cell bank (Figure 3). The length of the tube was set at twelve inches, and the inside of the tube was spray-painted matte black to minimize reflection from the tube material. By shining the flashlight directly onto the cell bank, we obtained a resistance for the illuminance of the flashlight. With the resistance from the direct light, we were able to calculate the flashlight's illuminance, and later determine the reflectivity of the test materials.

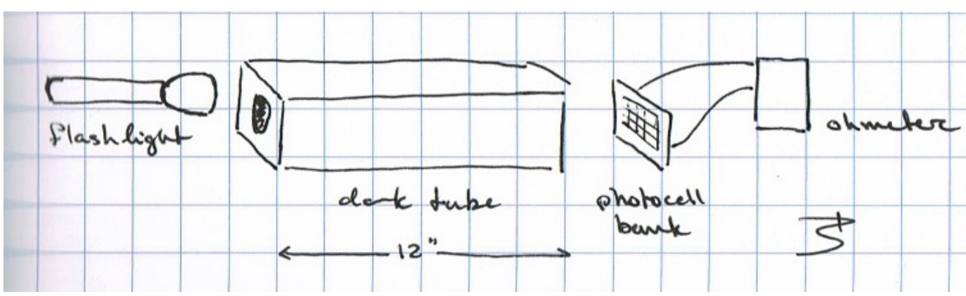

Figure 3: Sketch of calibration apparatus

During material testing, a dark box, with its interiors spray painted matte black, blocked out any ambient light, and held the flashlight and cell bank steady. The dark box and test sample were also placed on a piece of black felt to minimize any reflection from table surfaces (Figure 4).

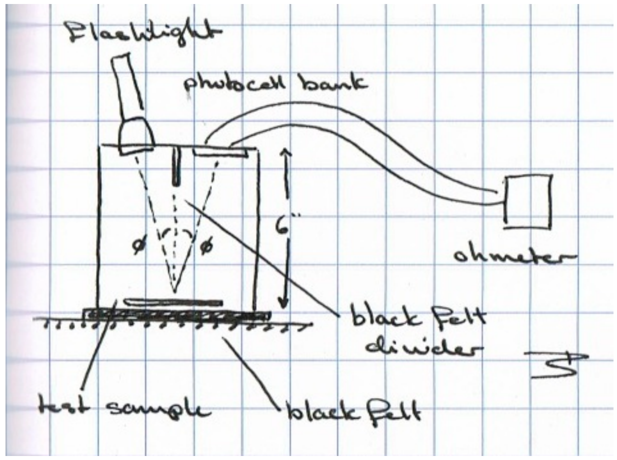

Figure 4: Sketch of reflectivity test apparatus

The distance between the flashlight and photocell bank was restricted to two inches (or one inch from the apparatus centre line to the centre of the cell bank or flashlight) so the small angle approximation could be used for the angle of incidence and reflection ($\sin\phi = 0.00291 \approx 0$). By ensuring the conditions of the small angle approximation were met, we were able to simulate a retro reflective test environment. Using the small angle approximation also meant that we could simplify the distance the light had to travel from the flashlight, to the sample, and then to the cell bank. If the small angle approximation did not apply, we would have had to take the horizontal distance from the flashlight to the cell bank into account. However, by creating an environment that we could apply the small angle approximation to, we could assume that the total distance the light had to travel was twice the height of the dark box, or twelve inches. A one-inch black felt divider was attached along the centre line of the dark box to minimize any light shining directly onto the cell bank from the flashlight.

2.1.2 Reflectivity Test Procedures

Before any we could commence with any reflectivity testing, we first had to assemble the proper equipment and apparatuses required for testing, such as the flashlight and cell bank. Next, we had to calibrate our test equipment so the test would provide us with accurate data. Equipment calibration involved focusing the flashlight hotspot onto the cell bank, and determining the illumination of the flashlight. Once the equipment has been calibrated, we were able to test the material samples in quick succession, and then determine the materials' reflectivity from the equation of the cell resistance vs. illuminance line.

1. Testing Equipment

For our testing, we used an AA Mini Maglite®, a cell bank constructed from nine PDV-P5002 photocells, two pre-constructed dark boxes, a piece of black felt, an ohmmeter, and a tape measure, used when calibrating the flashlight. We had pre-cut two-inch by three-inch pieces of aluminum that we used as backing plates for our test materials, ensuring the material surface was flat.

2. Flashlight Calibration

At a distance of one foot, the beam of the flashlight was focused so the brightest section of the beam, or the hotspot (Figure 5), was as similar in size to the cell bank as possible (Figure 6). For the flashlight we used, the minimum hotspot size was a little larger than the cell bank.

Figure 5: Beam pattern of the AA Mini Maglite® with the hotspot labeled

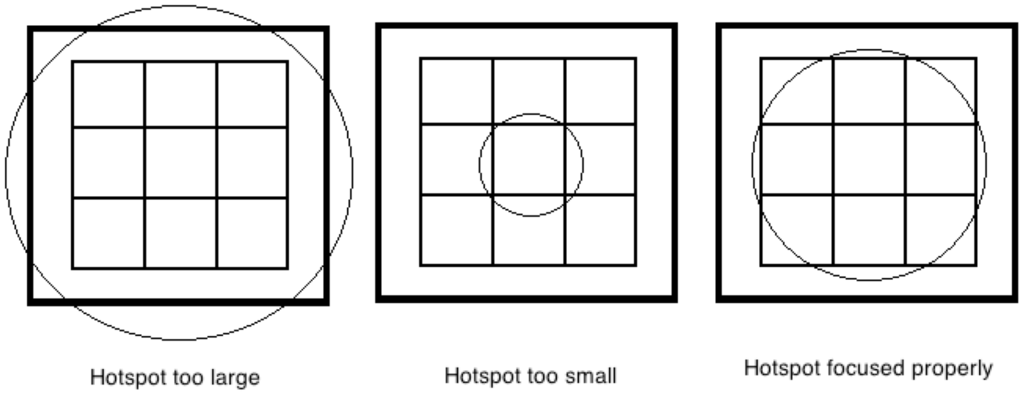

Figure 6: Illustration of incorrect and correct hotspot focusing onto the cell bank

Once the focus was set, the flashlight and the cell bank were placed into the dark tube (Figure 7), and the direct resistance (Ω_{direct}) was measured.

Figure 7: Final calibration apparatus (flashlight, dark tube, cell bank, and ohmmeter) in use

After Ω_{direct} had been recorded, multiple materials were tested in succession without obtaining a new Ω_{direct} for each different sample. Had the focus of the beam become accidentally readjusted, material testing would have ceased immediately, and a new Ω_{direct} should be found for further test samples. Fortunately, we did not have to recalibrate the flashlight during testing.

When taking resistance measurements, we allowed the ohmmeter to stabilize as much as possible, and avoided touching testing equipment during readings. The photocells are very sensitive, and the resistance readings could have been skewed as a result of minor movements of the testing apparatus.

3. Material Reflectivity Testing

To determine the reflectivity of a test sample, we laid the test material on the piece of black felt (Figure 8), and then positioned the dark box over top the test sample, ensuring the test sample was centred within the box. After the test sample box had been placed, the flashlight was inserted into the top of the dark box, making sure the hotspot was directed to the geometric centre of the test sample. With the flashlight secured, the cell bank was placed in the cutout of the dark box (Figure 9).

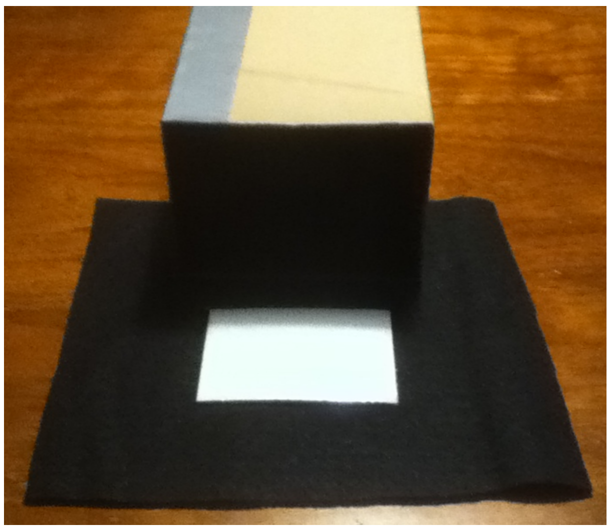

Figure 8: Test material (3M white reflective tape) on black felt in preparation for reflectivity testing

Figure 9: Flashlight inserted into dark box (sample inside), with the cell bank being positioned

With the test sample, flashlight, and cell bank in place, we read the resistance for the test sample (Ω_{sample}) from the ohmmeter.

4. Material Reflectivity Calculations

Once all materials had been tested, and the sample resistances recorded (Ω_1, Ω_2, Ω_3, etc.), the illumination of the flashlight (E_{direct}) and samples (E_1, E_2, E_3, etc.) were calculated from the equation of the cell resistance vs. illuminance line:

$$E = 10^{\frac{4.102 - \log \Omega}{2.221}}; [E] = \ lux, [\Omega] = \ Kohms$$

After we calculated the illuminations for each sample, the coefficient of reflectivity (Γ_{sample}) was simply the sample's illuminance divided by the direct illuminance:

$$\Gamma_{sample} = \frac{E_{sample}}{E_{direct}}$$

Through systematic test procedures, we were able to experimentally obtain the reflectivity of the 3M reflective tape, as well as the reflectivity of our design materials. By using the experimental apparatuses we designed, created, and manufactured, we calculated the amount of light reflecting from the test sample by measuring the cell resistance of the cell bank. Using the equation of the cell resistance vs. illuminance line, we then calculated the reflectivity for each material sample.

2.2 Durability Testing Methods & Procedures

The durability test was developed after the reflective test, and in a process similar to the design development procedure for the reflectivity test, initial sketches were created for the durability test to clarify the designs. The designs went through more iterations than the reflectivity test, due to issues with measuring test results. Once the designs had been refined, a single design was selected, and test apparatus constructed. However, the test apparatus abraded the samples too quickly, making data collection an issue. This forced another design to be implemented, and another set of test apparatus created. Once the quality of the test results had been verified, detailed testing procedures were created.

2.2.1 Development of the Durability Test & Apparatus Construction

Being able to determine the durability of potential coating materials was critical to the success of the project. Without any testing methods or procedures, we would have been unable to accurately assess the different materials, and choose the best design.

The durability test went through far more iterations than the reflectivity test. Initially, a reciprocating scuff test was investigated (Figure 10). For the reciprocating test, an electric motor, powering a drive wheel, would force a platform to move across the test sample surface. A piece of low-grit sandpaper to abrade the material surface would have been attached or bonded to the underside of the platform. However, the idea was abandoned due to the high complexity of sourcing an electric motor.

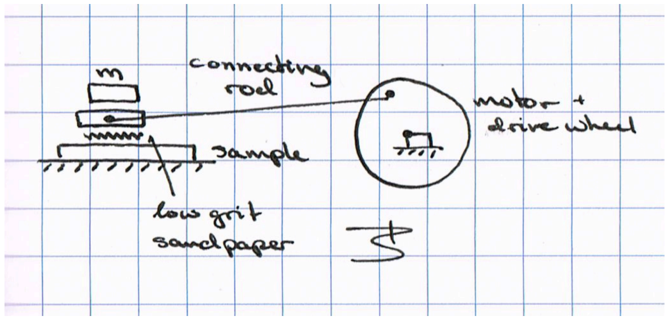

Figure 10: Sketch of reciprocating scuff test apparatus

The second iteration of the durability test involved using a palm sander within an enclosure (Figure 11), as the palm sander was inexpensive and easily obtained. Constructing the sander enclosure was also a simple task.

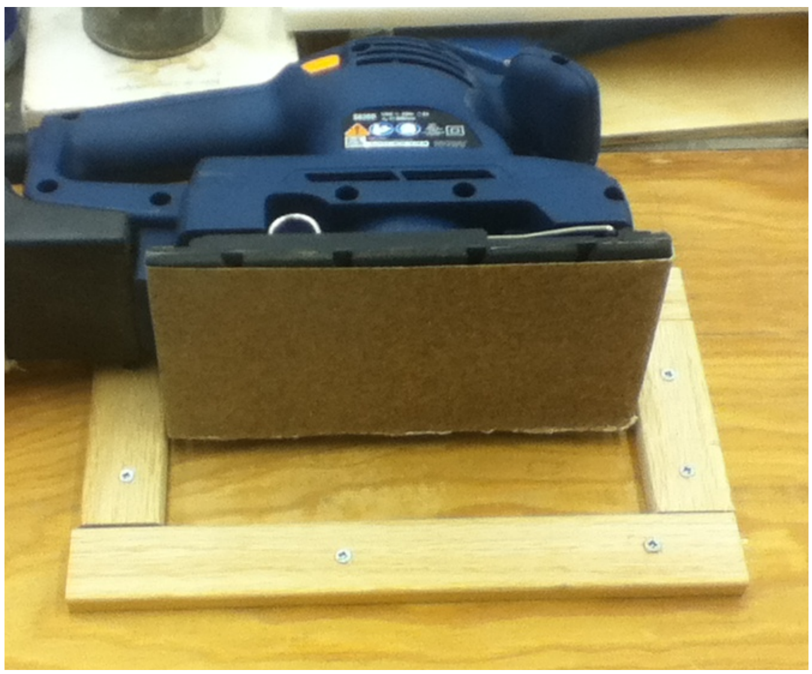

Figure 11: Palm sander and enclosure

The sample was placed flat on the board within the enclosure, the palm sander placed on top of the sample, and then the sander was run for a specified duration. Initial durability testing with the palm sander was undertaken to determine the maximum testing duration possible. Unfortunately, the palm sander destroyed the 3M tape samples (Figure 12) in a very short period of time (under three seconds).

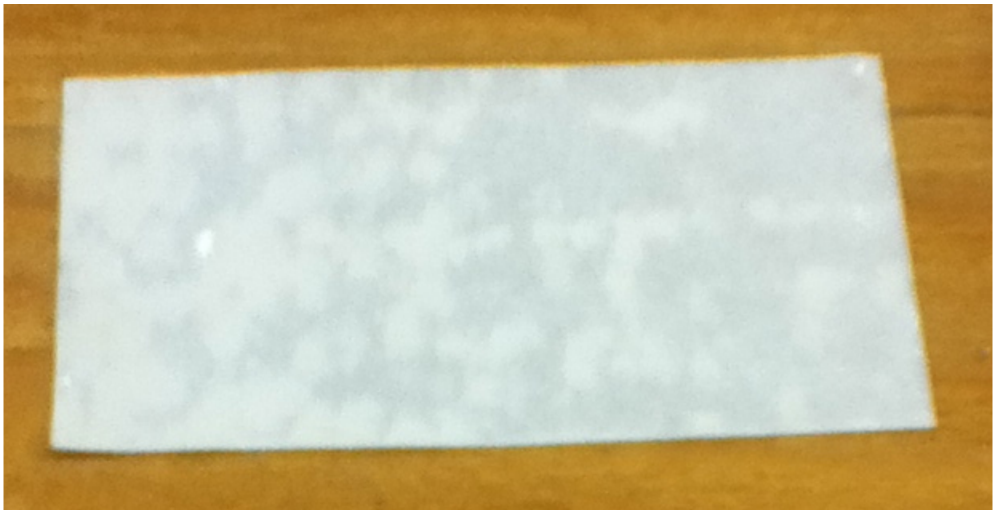

Figure 12: 3M white reflective tape after approximately two seconds of sander operation

Even though we could have tested materials for two or three seconds, there may have not been enough variation in the test results to differentiate different materials' durability. Also, any timing errors, even as little as half a second, represented a significant percentage of the nominal test duration.

The final durability test used a power drill driven belt sander and 120-grit sandpaper to abrade samples (Figure 13). Using high-grit sandpaper, and operating the drill at low speeds, we were able to increase the testing duration, thereby reducing the effects of timing errors.

Figure 13: Durability test apparatus, with a clamp secured to the platen

In the early stages of developing the durability test, a test to destruction method was considered. However, sample destruction is subjective, and the test would have to be stopped intermittently to check the level of wear on the sample. Instead of testing to destruction, we would abrade a sample for a set duration, and then measure sample's reflectivity using the reflectivity test (2.1). Testing the material's reflectivity after abrading provided us with the material's durability as a function of lost reflectivity.

The aluminum backing plate used to adhere sample coatings to simulated the bonding surface that the coating material would be bonded to, as aluminum shafts are used in cane construction. Having the sample material bonded to the aluminum backing plate also meant that the test sample could be easily moved from the reflectivity test, to the durability test, and then back to the reflectivity test.

For durability testing, we bonded the sample material (on the aluminum backing plate) to a testing block (Figure 14) with double-sided tape. The sample and test block was then placed sample down onto the running belt sander (Figure 15).

Figure 14: 3M white reflective tape bonded to an aluminum backing plate, adhered to the testing block with double-sided tape

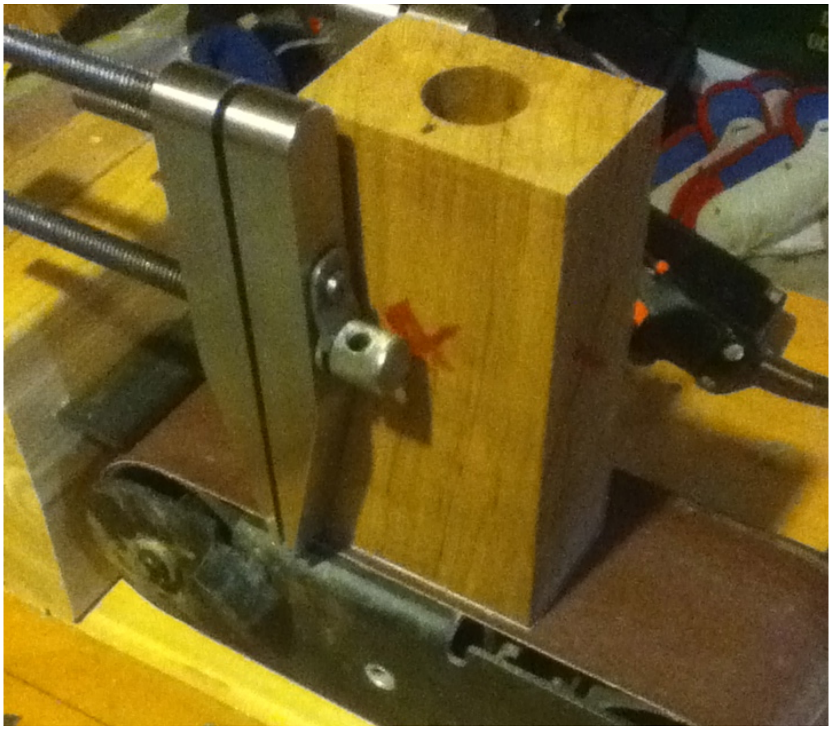

Figure 15: Testing block on belt sander

We secured clamps to the platen to prevent the testing block from falling off during testing. The testing block also had a hole cut into it so weights could be inserted into the block in order to maintain similar block and sample weights from test to test.

2.2.2 Durability Test Procedures

In order to undertake durability testing, we first had to collect and assemble our test equipment and apparatus, and set our test parameters to ensure we obtained accurate and useful data from the durability test. After the apparatus was assembled, and the test parameters set, we were able to being the durability test by abrading the material samples. Once the samples were abraded, and the testing completed, we calculated the durability for each test sample.

1. Testing Equipment

For our durability testing, we used the power drill drive belt sander, the testing block, double-sided tape, a scale to measure test sample weights, and a stopwatch. We already had test samples prepared from our reflectivity test, so we were able to adhere the sample to the test block.

2. Testing Parameters

The sample weight, belt speed, sandpaper grit, and testing time all remained constant over multiple tests to ensure that the test methods remained consistent. We used a nominal sample material plus block weight of 200 grams, a linear belt speed of 1.59 $^{m}/_{s}$, 120-grit sandpaper, and a ten second test duration during durability testing. Ideally, we could have increased the test duration to a minute, by decreasing the sample and block weight, belt speed, or increasing the grit-size. Increasing the test duration would have reduced the impact of timing errors, and increased the variation in the test results, allowing easier differentiation between the durability of different sample materials. When setting up the durability test, we had to ensure that the sample was not destroyed during testing, and adjusted our testing parameters accordingly. It would have been impossible to determine a material's reflectivity from destroyed samples.

3. Abrasion Testing

Once testing parameters were set, but before the sample was abraded, the reflectivity of the material was determined using the reflectivity test. Determining the baseline reflectivity provided us with the reflectivity of the material after zero seconds of abrasion, $\Gamma_{sample,\,0}$. After determining the pre-abraded reflectivity, the test sample was attached to the test block, and abraded using the durability test. The test sample and block was dropped onto the running belt sander to negate timing errors from sander startup and shutdown. Because the sample was dropped, we had to ensure the drop distance was as small as possible to minimize impact forces on the test sample.

After the sample had been abraded for ten seconds, the test material and block was picked up off the running belt sander. The drill was turned off after the sample had been removed from the belt. The reflectivity for the abraded test sample, $\Gamma_{\text{sample, 10}}$, was then determined once the backing plate and material had been removed from the test block. In order to collect extra data, we abraded the samples again to obtain further abraded reflective values ($\Gamma_{\text{sample, 20}}$). This was done by determining the sample's reflectivity, abrading the sample for another ten seconds, and then determining the sample's new reflectivity.

4. Material Durability Calculations

After calculating reflectivity values for a sample ($\Gamma_{\text{sample, 0}}$, $\Gamma_{\text{sample, 10}}$, $\Gamma_{\text{sample, 20}}$), we then calculated the material's durability as a function of reflectivity lost:

$$Percent\ Loss\ of\ Durability = \frac{\Gamma_{sample,0} - \Gamma_{sample,n}}{\Gamma_{sample,0}} \times 100$$

By developing the reflectivity and durability test methods and procedures, we successfully completed one of our main project objectives. Tests developed were also instrumental to the success of the project, as we used these tests to compare our material designs to the 3M white tape, and rate the designs accordingly.

3 Design Material Analysis & Selection

In selecting the best design material, we analyzed each of our seven coating designs based on our design criteria of weight, reflectivity, durability, and cost. The seven designs were then compared on a per criteria basis to the 3M white reflective tape, which was used on production canes at the time, in order to determine which design coating was the best. The goal for each design was to increase the lifetime of the cane, while minimizing weight, cost, and the loss of reflectivity.

3.1 Coating Design Descriptions

At the end of the concept development stage, we had seven design coatings that we would analyze in order to select the best design. The designs were: mirror film, shrink-wrap over 3M white tape, reflective aerosol spray on white paint, airport quality glass beads on white paint, standard highway beads on white paint, powdered glass beads on white paint, and wire mesh over 3M white tape.

3.1.1 Mirror Film

The intended use for mirror film (Figure 16) is to reflect light off of household windows. However, the reflective qualities of the mirror film can be used alert drivers to the cane user.

Figure 16: Mirror film

The mirror film would replace the 3M white reflective tape as the cane coating. Normally, the application method involves peeling off the protective layer from the back of the mirror film, then applying the film to the surface with a soap and water solution. However, a bonding agent or adhesive should be used when applying the mirror film to the cane to prevent the film from peeling.

3.1.2 Shrink-Wrap over 3M White Reflective Tape

The primary objective of applying shrink-wrap over the 3M white reflective tape (Figure 17) was to increase the durability of the coating. The 3M tape provides reflectivity, while the shrink-wrap adds protection against abrasion.

Figure 17: Shrink-wrap over 3M white reflective tape

This design will achieve suitable levels of reflectivity, as well as high levels of durability. Heat-shrink is applied by sliding a cut section of the shrink-wrap tube over the cane segment, and then heating the shrink-wrap until the wrap shrinks snugly around the cane shaft.

3.1.3 Reflective Aerosol Spray (Sphere Brite) on White Paint

By applying the reflective spray over white paint (Figure 18), we can achieve any colour coating desired, while maintaining the reflective properties that the 3M tape would provide.

Figure 18: Sphere Brite sprayed onto white paint

Paint would be applied to the cane segment, and then allowed to dry. Once cured, the paint would be coated with the reflective aerosol spray, and then the reflective coating allowed to cure.

3.1.4 Airport Quality Glass Beads on White Paint

Airport quality glass beads have high levels of reflectivity and durability, due to the minimal presence of air particles in the beads (less than 1%), and high surface smoothness. The glass beads are approximately 0.60 millimeters in diameter and have more than 95% roundness with a refractive index of 1.5. The cane segment would be painted, and then the glass beads immediately embedded into the paint layer (Figure 19).

Figure 19: Airport quality glass beads embedded into white paint

The paint provides an adhering surface to the glass beads, as well as providing the colour of the cane coating. The paint must be allowed to cure and harden. For optimum results, the glass beads have to be embedded at a depth 60% of the paint layer thickness [**2**].

3.1.5 Standard Highway Glass Beads on White Paint

Instead of airport quality glass beads (3.1.4), standard highway glass bead could be used as an alternative. Standard glass beads (Figure 20) have sand like texture, and used in a wide range of applications such as, traffic lines and traffic signs.

Figure 20: Standard highway glass beads embedded into white paint

Standard glass beads have a lower level of roundness compared to the airport quality, typically around 70%, and a value of reflective index that is equal to or greater than 1.5 [**2**]. Like the airport quality bead, the highway beads have to be imbedded into a layer of wet paint, at a depth 60% of the total layer thickness.

3.1.6 Powdered Glass Beads on White Paint

Powdered glass beads are another alternative to airport quality glass beads (3.1.4), or the standard highway glass beads (3.1.5). Powdered glass beads have a roundness level ranging between 65% to 95%, and a refractive index greater than or equal to 1.5. A cane can be painted any colour, and then the powdered glass bead embedded into the paint (Figure 21) to provide reflectivity.

Figure 21: Powdered glass beads embedded into white paint

As with the other glass beads, the powder must be embedded at a depth 60% of the total layer thickness.

3.1.7 Wire Mesh over 3M White Reflective Tape

Since the bottom section of a cane experience the most wear, applying a cage to those sections would greatly increase the lifetime of the cane by reducing the damage to the 3M tape (Figure 22).

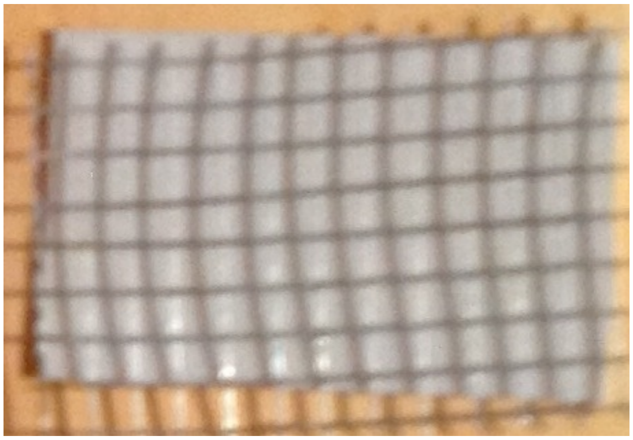

Figure 22: Mesh cage over 3M white reflective tape

Due to the open mesh of the cage, a majority of the tape's reflective property is maintained, with minimal weight and cost increases. The cage can also be marketed as an upgrade to a cane, especially for users that are especially tough on their canes. The wire mesh is applied to the finished canes in the form of a sleeve; moreover, the anti-corrosive property of the wire mesh will ensure the suitability of this design in various environments. The reflectivity of the cane should be maintained, but with a greatly increased durability.

The seven coating designs we developed in order to increase the lifetime of the cane by providing a more durable coating than the 3M white reflective tape. With each design, we also attempted to reduce the weight and cost of the cane, while developing a coating that had equal or greater reflectivity than the 3M white tape. The designs also had to conform to the constrains and limitations of the project. Once we finalized our conceptual designs, we then tested and analyzed each coating based on the coating's weight, reflectivity, durability, and cost, to determine which design was the best.

We also tested 3M orange and red reflective tape, at the request of the client. The 3M orange and red tapes are the second-most commonly used tapes, after the 3M white tape. The 3M orange and red tapes were also of a higher grade than the 3M white tape, and the client was curios as to how reflective and durable the orange and red reflective tapes compared to that of the white reflective tape.

3.2 Weight Comparison of Design Materials to the 3M White Reflective Tape

We were limited to a maximum allowable weight increase of our design coatings. A cane, with a design coating applied to it, could not weight more than 110% of the same cane with the 3M tape applied to it. We chose to standardize coating weights for a five-segment, 52-inch long, ½-inch diameter aluminum cane; typical specifications for the average adult. The weight of each material was weighed on a gram per square foot basis, and then the overall weight of the cane was then calculated using the individual coating weights (TABLE I).

TABLE I: WEIGHT COMPARISON OF ALL CONCEPTUAL DESIGNS TO THE CURRENT 3M WHITE REFLECTIVE TAPE

	Name	Weight of 52" Cane, 1/2" Aluminum with Material Coating [grams]	% Weight Reduction Compared to Tape
AmbuTech Materials (Reflective Tape)	3M White Tape	306.86	-
New Materials	Mirror Film	295.88	3.58%
	Shrink Wrap + White Tape	319.16	-4.01%
	Reflective Aerosol Spray + White Paint	299.56	2.38%
	Airport Quality Reflective Beads + White Paint	362.66	-18.18%
	Standard Highway Reflective Beads + White Paint	313.04	-2.01%
	Powder Reflective Beads + White Paint	303.23	1.18%
	Cage (Bottom Section only) + White Tape	314.59	-2.52%

Each conceptual design was found to be within the 10% net cane weight increase, except for the airport reflective glass beads, highlighted in red. The three green cells highlight the conceptual designs that were lighter than the existing 3M tape. Cells coloured orange are materials that are heavier than the 3M white reflective tape, but within the acceptable weight increase.

3.3 Reflectivity Comparison of Design Materials to the 3M White Reflective Tape

The experimental equipment designed and prototyped by the team was used to measure the reflectivity of all design materials. Prior to this project, no quantifiable reflectivity metrics for the 3M reflective white tape existed. As a result, we needed to measure the reflectivity of the current materials used at AmbuTech in order to establish a baseline reflectivity. As the reflectivity and durability testing took place concurrently, reflective values for the test samples after zero seconds, ten seconds, and twenty seconds of abrasion were obtained. However, only pre-abraded reflectivity results were used to evaluate the reflective performance of each design material. In order to improve the statistical accuracy of the test results, three samples for each design material were tested.

After reflectivity testing, we found that the 3M white reflective tape (TABLE II – highlighted in grey) outperformed each design material (highlighted in red) except for the mirror film (highlighted in green). Because the majority of the design materials were less reflective than the white reflective tape, the designs considered did not show must promise. However, the reflectiveness of the design materials was comparable to that of the 3M red reflective tape currently used in the manufacturing of AmbuTech canes. Therefore, the reflectivity of each of the design materials was within acceptable limits of reflectivity used in industry. This gave us confidence as to the selection of our design materials.

TABLE II: REFLECTIVITY COMPARISON OF ALL CONCEPTUAL DESIGNS TO THE CURRENT 3M WHITE REFELCTIVE TAPE AFTER 0 SECONDS OF ABRASION TESTING

	Name	Test Sample	Measured Resistance [Kohm]	Calculated Illuminance [lux]	Calculated Reflectivity	Average Reflectivity	Standard Deviation of Material Reflectivity	% Reflectivity Increase Compared to White Tape
AmbuTech Materials (Reflective Tape)	3M White Tape	1	27.1	15.912	0.371	0.357	0.013	**0.00%**
		2	30.6	15.065	0.351			
		3	31.5	14.870	0.347			
	3M Red	1	46.2	12.515	0.292	0.288	0.003	**-19.19%**
		2	48.0	12.301	0.287			
		3	48.6	12.232	0.285			
	3M Orange	1	42.2	13.035	0.304	0.304	0.002	**-14.67%**
		2	42.9	12.939	0.302			
		3	41.4	13.148	0.307			
New Materials	Mirror Film	1	21.2	17.772	0.415	0.414	0.003	**16.05%**
		2	21.7	17.586	0.410			
		3	21.0	17.848	0.416			
	Shrink Wrap + White Tape	1	33.9	14.386	0.336	0.337	0.003	**-5.48%**
		2	34.0	14.367	0.335			
		3	32.9	14.581	0.340			
	Reflective Aerosol Spray + White Paint	1	58.9	11.218	0.262	0.258	0.004	**-27.74%**
		2	61.1	11.035	0.257			
		3	63.1	10.876	0.254			
	Airport Quality Reflective Beads + White Paint	1	38.4	13.601	0.317	0.313	0.004	**-12.11%**
		2	39.8	13.384	0.312			
		3	40.3	13.309	0.310			
	Standard Highway Reflective Beads + White Paint	1	47.5	12.359	0.288	0.287	0.001	**-19.53%**
		2	48.1	12.289	0.287			
		3	48.5	12.244	0.286			
	Powder Reflective Beads + White Paint	1	47.5	12.359	0.288	0.296	0.011	**-16.85%**
		2	40.7	13.250	0.309			
		3	46.2	12.515	0.292			
	Cage (Bottom Section only) + White Tape	1	39.2	13.475	0.314			**-11.82%**
*Direct Readings			3.0	42.9				

Below is a photo of the samples before abrasion testing (Figure 23). The samples in the photo are: reflective aerosol spray on white paint (1), powdered glass beads on white paint (2), standard highway glass beads on white paint (3), airport quality glass beads on white paint (4), shrink-wrap over 3M white reflective tape (5), 3M red reflective tape (6), 3M orange reflective tape (7), mirror film (8), and 3M white reflective tape (9).

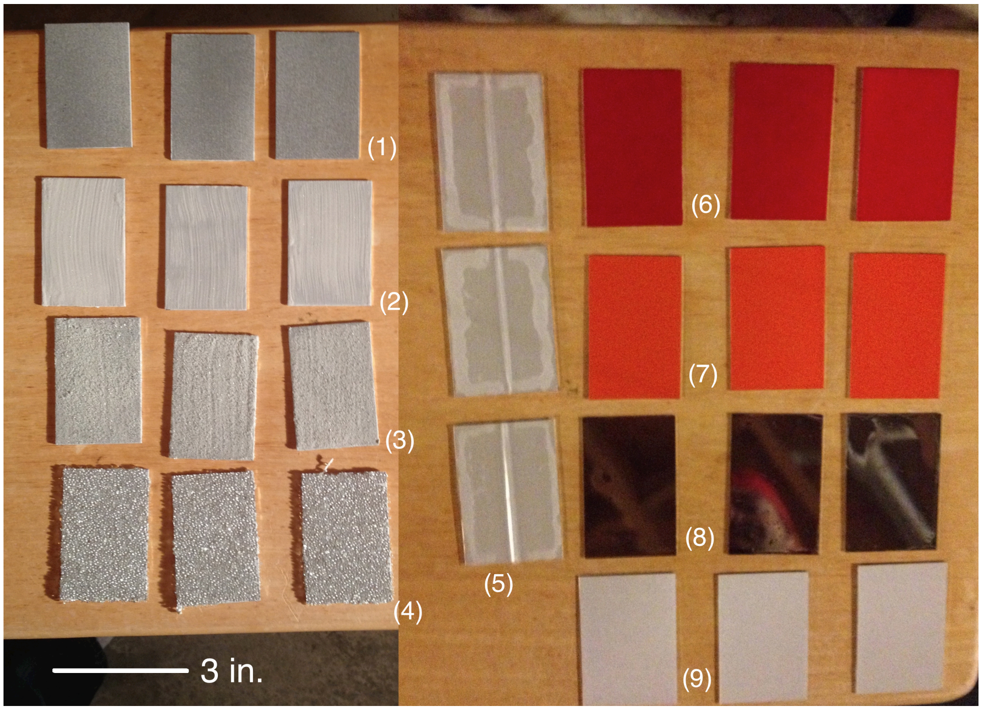

Figure 23: Samples before abrasion testing

After determining the reflectivity for the pre-abraded samples, the samples were then abraded, using the durability test, and the reflectivity for the newly abraded samples calculated. The percent difference in reflectivity values was the durability for each sample.

3.4 Durability Comparison of Design Materials to the 3M White Reflective Tape

As per the durability test (2.2), the reflectivity data collected was used to determine the durability for the various coating materials. Only the results of the un-abraded reflectivity test, and the ten-second reflectivity test, were used in determining each material's durability (TABLE III), due to the poor data after twenty seconds of abrasion testing. The percent loss of durability, averaged for over the three samples, was compared to that of the 3M white tape.

TABLE III: DURABILITY COMPARISON OF ALL CONCEPTUAL DESIGNS TO THE CURRENT 3M WHITE TAPE

	Material	Average Reflectivity of Material (0 Sec Abrasion)	Average Reflectivity of Material (10 Sec Abrasion)	Average Percent Change in Reflectivity	% Durability Increase Compared to White Tape (10 Sec Abrasion)
AmbuTech Materials (Reflective Tape)	3M White Tape	0.357	0.330	-0.074	0.00%
New Materials	Mirror Film	0.414	0.394	-0.048	2.53%
	Shrink Wrap + White Tape	0.337	0.324	-0.040	3.41%
	Reflective Aerosol Spray + White Paint	0.258	0.248	-0.038	3.53%
	Airport Quality Reflective Beads + White Paint	0.313	Fail	Fail	Fail
	Standard Highway Reflective Beads + White Paint	0.287	0.264	-0.080	-0.65%
	Powder Reflective Beads + White Paint	0.296	0.260	-0.122	-4.80%
	Cage (Bottom Section only) + White Tape	0.314	0.313	-0.004	6.93%

The cage over 3M white tape was the most durable, losing 6.93% less reflectivity than the 3M white tape. The cage was also abraded for thirty seconds, not just the ten seconds each other material was abraded for, showing that the cage was significantly more durable than originally expected. The other designs that were more durable than the 3M white tape were the reflective aerosol spray on white paint, shrink-wrap over 3M white tape, and mirror film, and were all considered viable designs.

The airport quality, standard highway, and powdered glass beads on white paint all failed to exceed the durability of the 3M white tape. In the case of the airport quality beads, the beads were dislodged from the paint during durability testing. The highway and powdered glass beads stayed embedded in the paint during testing, but the sandpaper caused the paint, in sections, to completely fleck off of the backing plate.

We also plotted the average reflectivity for each material against the abrasion duration (Figure 24). Most materials lost reflectivity at relatively uniform rates, but the reflectivity of some materials actually increased after a certain length of abrasion. The increase in reflectivity was caused by the aluminum backing plate being exposed, either because the coating failed, or sections of the coating were removed from the plate during testing.

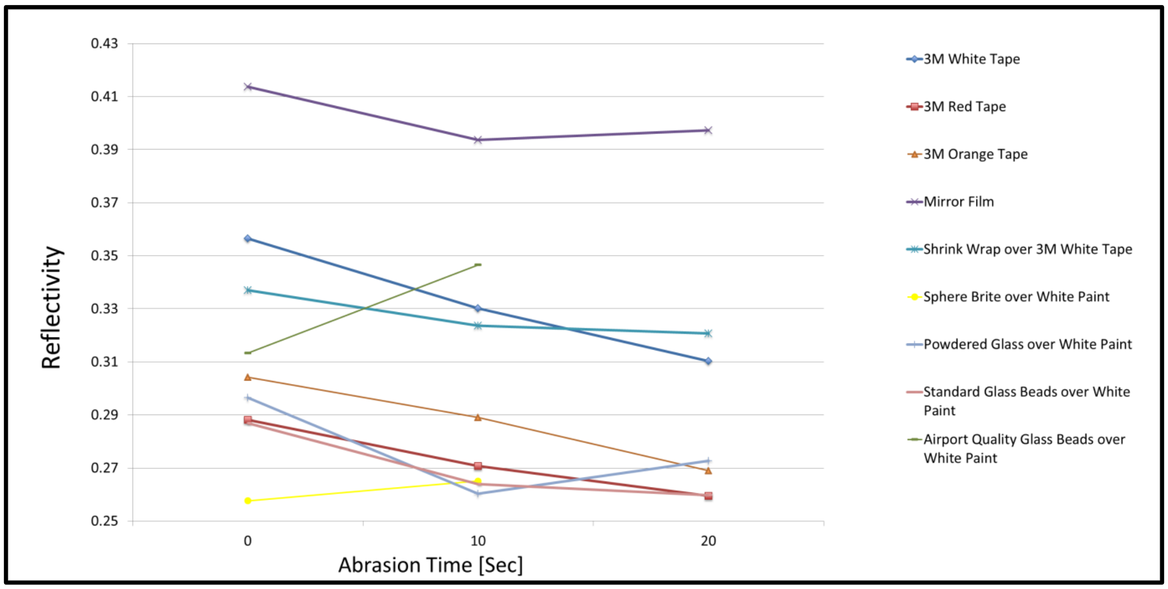

Figure 24: Average reflectivity of each material after 0, 10, and 20 seconds of abrasion testing

Each design that did not incorporate reflective beads was more durable than the existing tape. In the case of the powdered glass beads, and the standard highway glass beads, sample failure was due to the paint being stripped off of the aluminum backing plate instead of the glass beads being pulled out of the paint layer. However, we were only to acquire standard indoor/outdoor house paint for testing, instead of the industrial paint used on highways. Changing the type of paint used could increase the durability for the glass bead designs, but may increase the cost as well.

3.5 Cost Comparison of Design Materials to the 3M White Reflective Tape

Cost is another constraint of the design project, as the total cost increase of a cane cannot exceed $1.00 when a design material is used instead of the 3M white tape. Costs were standardized for the same cane dimensions (5 section aluminum cane, 52 inches long, ½-inch diameter) as that used in the weight comparisons (3.2).

Most of the design materials were less expensive than the 3M white tape (TABLE IV – highlighted in green). Materials that were more expensive than the white tape, but did not exceed the cost limitation, are highlighted in orange, and materials that were more expensive than the design limitation of $1.00 are highlighted in red.

TABLE IV: COST COMPARISON OF ALL CONCEPTUAL DESIGNS TO THE CURRENT 3M WHITE

	Material	Cost [$CND] of Material Cane Coating for a 52" Cane, 1/2" Aluminum	Cost Reduction [$CND]
AmbuTech Materials (Reflective Tape)	3M White Tape	$3.648	-
New Materials	Mirror Film	$2.721	$0.927
	Shrink Wrap + White Tape	$4.955	-$1.307
	Reflective Aerosol Spray + White Paint	$3.459	$0.189
	Airport Quality Reflective Beads + White Paint	$2.787	$0.861
	Standard Highway Reflective Beads + White Paint	$2.751	$0.897
	Powder Reflective Beads + White Paint	$2.802	$0.846
	Cage (Bottom Section only) + White Tape	$3.680	-$0.032

Significant cost savings were found with the mirror film, airport quality reflective glass beads with white paint, standard highway reflective glass beads with white paint, and the powder reflective glass beads with white paint, each of which exceeded $0.80 in savings. Another cheaper alternative to the current reflective tape is the reflective aerosol spray with white paint. It was not a surprise to the design team that the addition of the cage to the existing 3M white tape would increase the cost. Although the cost of the cage design was higher, the material did not exceed the cost limitations of the project. Finally, the shrink-wrap with white 3M reflective tape was found to exceed the cost limitation of the project.

3.6 Overall Comparison of each Design Material to the 3M White Reflective Tape

Although the weight, reflectivity, durability, and cost comparisons have each been covered as a whole, we need to compare each design directly to the 3M white tape using the design four metrics. By comparing each design directly to the 3M tape, we identified in which metrics the design outperformed the 3M tape.

3.6.1 Mirror Film vs. 3M White Reflective Tape

The mirror film conceptual design outperformed the existing 3M white tape in each quantifiable metric (TABLE V), and was considered a viable alternative to the 3M white reflective tape. One potential issue with the mirror film is that it may not be 'white' enough to meet colour standards.

TABLE V: COMPARISON OF THE MIRROR FILM TO 3M WHITE REFELCTIVE TAPE

Weight	3M White Tape	Mirror Film
Weight of 52" Cane, 1/2" Aluminum with Material Coating [grams]	306.86	295.88
% Weight Reduction Compared to White Tape	-	**3.58%**

Durability	3M White Tape	Mirror Film
Average Reflectivity of Material (0 Sec Abrasion)	0.357	0.414
Average Reflectivity of Material (10 Sec Abrasion)	0.330	0.394
% Change In Reflective (0 to 10 Sec Abrasion)	-7.36%	-4.84%
% Durability Increase Compared to White Tape	-	**2.53%**

Reflectivity	3M White Tape	Mirror Film
Average Reflectivity	0.357	0.414
% Reflectivity Increase Compared to White Tape	-	**16.05%**

Cost	3M White Tape	Mirror Film
Cost ($CND) of Material Cane Coating for a 52" Cane, 1/2" Aluminum	$3.648	$2.721
% Cost Decrease Compared to White Tape	-	**$0.927**

3.6.2 Shrink-Wrap over 3M White Reflective Tape vs. 3M White Reflective Tape

The objective of putting shrink-wrap over top of the white tape was to increase the durability of the cane, which the design was successful in achieving. However, the weight, reflectivity and cost of the design suffered in comparison to the white reflective tape on its own (TABLE VI). Most notably, the design failed to remain within the $1.00 cost increase limitation of the design project.

TABLE VI: COMPARISON OF THE SHRINK-WRAP OVER 3M WHITE REFLECTIVE TAPE TO 3M WHITE REFELCTIVE TAPE

Weight	3M White Tape	Shrink Wrap + White Tape
Weight of 52" Cane, 1/2" Aluminum with Material Coating [grams]	306.86	319.16
% Weight Reduction Compared to White Tape	-	**-4.01%**

Durability	3M White Tape	Shrink Wrap + White Tape
Average Reflectivity of Material (0 Sec Abrasion)	0.357	0.337
Average Reflectivity of Material (10 Sec Abrasion)	0.330	0.324
% Change In Reflective (0 to 10 Sec Abrasion)	-7.36%	-3.96%
% Durability Increase Compared to White Tape	-	**3.41%**

Reflectivity	3M White Tape	Shrink Wrap + White Tape
Average Reflectivity	0.357	0.337
% Reflectivity Increase Compared to White Tape	-	**-5.48%**

Cost	3M White Tape	Shrink Wrap + White Tape
Cost ($CND) of Material Cane Coating for a 52" Cane, 1/2" Aluminum	$3.648	$4.955
% Cost Decrease Compared to White Tape	-	**-$1.307**

3.6.3 Reflective Aerosol Spray on White Paint vs. 3M White Reflective Tape

The reflective aerosol spray over white paint has a lower weight, higher durability, and lower cost than the white reflective tape (TABLE VII), but the spray was not as reflective.

TABLE VII: COMPARISON OF THE REFLECTIVE AEROSOL SPRAY ON WHITE PAINT TO 3M WHITE REFELCTIVE TAPE

Weight	3M White Tape	Reflective Aerosol Spray + White Paint
Weight of 52" Cane, 1/2" Aluminum with Material Coating [grams]	306.86	299.56
% Weight Reduction Compared to White Tape	-	**2.38%**

Durability	3M White Tape	Reflective Aerosol Spray + White Paint
Average Reflectivity of Material (0 Sec Abrasion)	0.357	0.258
Average Reflectivity of Material (10 Sec Abrasion)	0.330	0.248
% Change In Reflective (0 to 10 Sec Abrasion)	-7.36%	-3.84%
% Durability Increase Compared to White Tape	-	**3.53%**

Reflectivity	3M White Tape	Reflective Aerosol Spray + White Paint
Average Reflectivity	0.357	0.258
% Reflectivity Increase Compared to White Tape	-	**-27.74%**

Cost	3M White Tape	Reflective Aerosol Spray + White Paint
Cost ($CND) of Material Cane Coating for a 52" Cane, 1/2" Aluminum	$3.648	$3.459
% Cost Decrease Compared to White Tape	-	**$0.189**

3.6.4 Airport Quality Reflective Glass Beads on White Paint vs. 3M White Reflective Tape

The airport quality reflective glass beads on white only outperformed the white tape in terms of cost (TABLE VIII). The weight of the reflective coating was higher, and the reflectivity and durability lower than the 3M reflective tape.

TABLE VIII: COMPARISON OF THE AIRPORT QUALITY GLASS BEADS ON WHITE PAINT TO 3M WHITE REFELCTIVE TAPE

Weight	3M White Tape	Airport Quality Reflective Beads + White Paint
Weight of 52" Cane, 1/2" Aluminum with Material Coating [grams]	306.86	362.66
% Weight Reduction Compared to White Tape	-	**-18.18%**

Durability	3M White Tape	Airport Quality Reflective Beads + White Paint
Average Reflectivity of Material (0 Sec Abrasion)	0.357	0.313
Average Reflectivity of Material (10 Sec Abrasion)	0.330	Fail
% Change In Reflective (0 to 10 Sec Abrasion)	-7.36%	Fail
% Durability Increase Compared to White Tape	-	**Fail**

Reflectivity	3M White Tape	Airport Quality Reflective Beads + White Paint
Average Reflectivity	0.357	0.313
% Reflectivity Increase Compared to White Tape	-	**-12.11%**

Cost	3M White Tape	Airport Quality Reflective Beads + White Paint
Cost ($CND) of Material Cane Coating for a 52" Cane, 1/2" Aluminum	$3.648	$2.787
% Cost Decrease Compared to White Tape	-	**$0.861**

3.6.5 Standard Highway Glass Beads on White Paint vs. White 3M Tape

Similar to the previous design, the standard highway reflective glass beads with white paint outperformed the existing 3M white tape in terms of cost alone (TABLE IX). Compared to the white reflective tape, the standard highway glass bead coating had lower durability and reflectivity, and a higher weight.

TABLE IX: COMPARISON OF THE STANDARD HIGHWAY GLASS BEADS ON WHITE PAINT TO 3M WHITE REFELCTIVE TAPE

Weight	3M White Tape	Standard Highway Reflective Beads + White Paint
Weight of 52" Cane, 1/2" Aluminum with Material Coating [grams]	306.86	313.04
% Weight Reduction Compared to White Tape	-	**-2.01%**

Durability	3M White Tape	Standard Highway Reflective Beads + White Paint
Average Reflectivity of Material (0 Sec Abrasion)	0.357	0.287
Average Reflectivity of Material (10 Sec Abrasion)	0.330	0.264
% Change In Reflective (0 to 10 Sec Abrasion)	-7.36%	-8.02%
% Durability Increase Compared to White Tape	-	**-0.65%**

Reflectivity	3M White Tape	Standard Highway Reflective Beads + White Paint
Average Reflectivity	0.357	0.287
% Reflectivity Increase Compared to White Tape	-	**-19.53%**

Cost	3M White Tape	Standard Highway Reflective Beads + White Paint
Cost ($CND) of Material Cane Coating for a 52" Cane, 1/2" Aluminum	$3.648	$2.751
% Cost Decrease Compared to White Tape	-	**$0.897**

3.6.6 Powder Reflective Glass Beads on White Paint vs. White 3M Tape

The powder reflective glass beads on white paint had a lower weight and lower material cost than the 3M white tape (TABLE X). The glass bead coating was less reflective and less durable than the tape.

TABLE X: COMPARISON OF THE POWDERED GLASS BEADS ON WHITE PAINT TO 3M WHITE REFELCTIVE TAPE

Weight	3M White Tape	Powder Reflective Beads + White Paint
Weight of 52" Cane, 1/2" Aluminum with Material Coating [grams]	306.86	303.23
% Weight Reduction Compared to White Tape	-	**1.18%**

Durability	3M White Tape	Powder Reflective Beads + White Paint
Average Reflectivity of Material (0 Sec Abrasion)	0.357	0.296
Average Reflectivity of Material (10 Sec Abrasion)	0.330	0.260
% Change In Reflective (0 to 10 Sec Abrasion)	-7.36%	-12.17%
% Durability Increase Compared to White Tape	-	**-4.80%**

Reflectivity	3M White Tape	Powder Reflective Beads + White Paint
Average Reflectivity	0.357	0.296
% Reflectivity Increase Compared to White Tape	-	**-16.85%**

Cost	3M White Tape	Powder Reflective Beads + White Paint
Cost ($CND) of Material Cane Coating for a 52" Cane, 1/2" Aluminum	$3.648	$2.802
% Cost Decrease Compared to White Tape	-	**$0.846**

3.6.7 Cage over 3M White Reflective Tape vs. 3M White Reflective Tape

The cage (covering the bottom section of the cane only) over the white 3M tape outperformed the 3M white tape in terms of durability only (TABLE XI). This was expected, as the design goal of the cage was to greatly increase the durability of the cane, even though the cost, weight, and durability would be impacted. The cost was increased compared to the 3M tape alone, and the cost of the cage remained under the $1.00 increase design constraint. The overall cane weight increased, and the reflectivity decreased, as anticipated.

TABLE XI: COMPARISON OF THE CAGE OVER 3M WHITE REFELCTIVE TAPE TO 3M WHITE REFELCTIVE TAPE

Weight	3M White Tape	Cage (Bottom Section only) + White Tape	Durability	3M White Tape	Cage (Bottom Section only) + White Tape
Weight of 52" Cane, 1/2" Aluminum with Material Coating [grams]	306.86	314.59	Average Reflectivity of Material (0 Sec Abrasion)	0.357	0.314
			Average Reflectivity of Material (10 Sec Abrasion)	0.330	0.313
% Weight Reduction Compared to White Tape	-	-2.52%	% Change In Reflective (0 to 10 Sec Abrasion)	-7.36%	-0.44%
			% Durability Increase Compared to White Tape	-	6.93%

Reflectivity	3M White Tape	Cage (Bottom Section only) + White Tape	Cost	3M White Tape	Cage (Bottom Section only) + White Tape
Average Reflectivity	0.357	0.314	Cost ($CND) of Material Cane Coating for a 52" Cane, 1/2" Aluminum	$3.648	$3.680
% Reflectivity Increase Compared to White Tape	-	-11.82%	% Cost Decrease Compared to White Tape	-	-$0.032

By comparing each design coating directly to the 3M white tape, we could determine which coatings were better than the 3M white reflective tape. Of all seven designs, only the mirror film outperformed the 3M tape in all design considerations. Although some designs did not outperform the 3M tape in all four design considerations, such as the reflective spray or powdered beads on white paint, we were still optimistic that these designs could be viable solutions. By using a weighted decision matrix, we were able to analyze how each design consideration contributed to an overall score for each coating design.

3.7 Material Concept Selection

The weighting matrix was developed with input from the client, and the matrix greatly aided in the ranking and selection of different concepts. A weighted matrix (TABLE XII) was a tool we used to determine the relative weight or importance of each design criteria. By systematically comparing the criteria to each other, and choosing which criteria is more desired, we determined how important each criteria is to the project.

TABLE XII: WEIGHTED MATRIX FOR THE SCORING OF CONCEPTUAL DESIGNS

Weighting Criteria Matrix for Design Material		Low Weight	High Durability	High Reflectivity	Low Surface Roughness	Low Material Cost	High Material Availability	Aesthetics
		A	B	C	D	E	F	H
A	Low Weight		A	A	A	A	A	A
B	High Durability			C	B	B	B	H
C	High Reflectivity				C	C	C	H
D	Low Surface Roughness					E	F	H
E	Low Material Cost						F	H
F	High Material Availability							H
H	Aesthetics							
Total Hits		6	3	4	0	1	2	5
Weightings (%)		28.6	14.3	19.0	0.0	4.8	9.5	23.8

The weightings indicates the significance of each need; the higher the weight, the more important that aspect is to the overall design. The highest score of 28.6% indicates that low weight is of high importance, and should be prioritized in selecting the final design concept. The needs were identified by the project team and were scored in conjunction with representatives of AmbuTech in order to attain accurate weightings and expectations of the client.

For material selection, a weighted scoring matrix (TABLE XIII) was developed so all the different designs could be examined simultaneously. The weighted scoring matrix is an extension of the weighted evaluation matrix, and includes all the quantifiable metrics: weight, durability, reflectivity, and cost. Low surface roughness was listed in a previous weighted matrix, but it received a 0% weighting from the client. The aesthetics of the cane are listed, but were not used in the evaluation of the design coatings, due the subjective nature of a coating's visual aesthetic. The metrics have been normalized to the current 3M white tape to provide a more accurate description of how the conceptual designs compare to the current method.

TABLE XIII: WEIGHTED SCORES OF ALL CONCEPTUAL DESIGNS COMPARED TO THE CURRENT 3M WHITE REFLECTIVE TAPE

Conceptual Design		3M White Tape		Mirror Film		Shrink Wrap + White Tape		Reflective Aerosol Spray + White Paint		Airport Quality Reflective Beads + White Paint		Standard Highway Reflective Beads + White Paint		Powder Reflective Beads + White Paint		Cage (Bottom Section only) + White Tape	
Selection Criteria	Weight (%)	Normalized Score	Weighted Score	Normalized Score	Weighted Score	Normalized Score	Weighted Score	Normalized Score	Weighted Score	Normalized Score	Weighted Score	Normalized Score	Weighted Score	Normalized Score	Weighted Score	Normalized Score	Weighted Score
Low Weight	28.6	1	28.6%	1.037	29.6%	0.961	27.5%	1.024	29.3%	0.846	24.2%	0.980	28.0%	1.012	28.9%	0.975	27.9%
High Durability	14.3	1	14.3%	1.027	14.7%	1.037	14.8%	1.038	14.8%	Fail	Fail	0.993	14.2%	0.948	13.5%	1.080	15.4%
High Reflectivity	19.0	1	19.0%	1.161	22.1%	0.960	18.3%	1.024	19.5%	0.818	15.6%	0.980	18.7%	1.012	19.3%	0.975	18.6%
Low Material Cost	4.8	1	4.8%	1.341	6.4%	0.736	3.5%	1.055	5.0%	1.309	6.2%	1.326	6.3%	1.302	6.2%	0.991	4.7%
High Material Availability	9.5	1	9.5%	1.000	9.5%	1.000	9.5%	1.000	9.5%	1.000	9.5%	1.000	9.5%	1.000	9.5%	1.000	9.5%
Aesthetics	23.8	1	23.8%	0.875	20.8%	0.875	20.8%	1.000	23.8%	0.500	11.9%	0.750	17.9%	0.875	20.8%	0.250	6.0%
Total Score (without asthetics)		76.19%		82.32%		73.60%		78.14%		55.52%		76.69%		77.45%		76.10%	
Total Score (including asthetics)		100.00%		103.15%		94.43%		101.95%		67.42%		94.55%		98.29%		82.06%	
Rank		Current Method		1		6		2		7		4		3		5	

Four of the seven conceptual designs (highlighted in green) served as viable solutions to the design problem. These solutions, in order of ascending ranking, were the mirror film, reflective aerosol spray over white paint, powdered glass beads over white paint, and standard highway glass beads over white paint. The cage (highlighted in grey) was comparable to the existing design, and so had very little value added over the 3M white tape. The shrink-wrap over white tape design, and the airport quality reflective beads on white paint design, both highlighted in red, scored worse than the 3M reflective tape, and were thus discarded.

We recommend the mirror film as the best reflective material to replace the existing 3M reflective tape, based on the results of the weighted scoring matrix. With and overall score of 82.32%, the mirror film outscored all other design coatings, and the 3M white reflective tape, which only scored 76.19%. The next highest scoring design, the reflective spray on white paint, had a score of 78.14%, 20.5 percentage points higher than the 3M white tape. The other two viable designs, powdered glass beads, and highway glass beads, each on white tape, scored 77.45% and 76.69%, respectively.

We have successfully achieved one of our project objectives by identifying a valid cane-coating alternative to the 3M white reflective tape, and have also validated three other coating designs to be used on mobility canes.

4 Application Cell

Originally, a complete design of an application process and cell was required for the project. However, the scope of the project was changed due to time constraints, and recommendations as to application processes and cells. We have made application cell recommendations for the four viable design coatings: mirror film, reflective spray on white paint, powdered glass beads on white paint, and standard highway beads on white paint. Although only recommendations have been made, such recommendations were made with design criteria for the cell in mind.

4.1 Weighted Criteria Matrix for Cell Design

The weighting matrix (TABLE XIV) for cell design was also developed with the aid of the client, and was used to assist in the ranking and selection of different application cell concepts once a final reflective material was chosen. After we identified the needs involved in designing an application cell, the needs were scored in conjunction with representatives of AmbuTech, in order to attain accurate weightings, and expectations, of the client.

TABLE XIV: WEIGHTED MATRIX FOR THE SCORING OF CONCEPTUAL DESIGN CELLS

Weighting Criteria Matrix for Cell Design		Low Manufacturing Time	Small Footprint	Ease of Application	Low Equipment Cost	Ease of Integration	Safe for Employees	Low Maintenance Cost
		A	B	C	D	E	F	G
A	Low Manufacturing Time		A	C	A	A	F	A
B	Small Footprint			C	B	B	F	B
C	Ease of Application				C	C	F	C
D	Low Equipment Cost					E	F	G
E	Ease of Integration						F	G
F	Safe for Employees							F
G	Low Maintenance Cost							
Total Hits		4	3	5	0	1	6	2
Weightings		19.0	14.3	23.8	0.0	4.8	28.6	9.5

Similar to the matrix for reflective materials, the weightings indicate the significance of each need, the higher the weight, the more important that aspect is to the overall design. The highest score of 28.6% indicates that safety has the highest importance, and should be prioritized in selecting the final design concept. The results of the weighted matrix for cell design were taken into account when the application cell recommendations were made fro the design coatings.

4.2 Mirror Film

The mirror film can be applied in a similar fashion to the current 3M tape, such as with roller machines and tape dispensers. Since the film is provided a roll, the mirror film can be cut to strips that will fit in the current tape dispensers. Alternatively, a new dispenser machine could be purchased, although the cost of obtaining such a machine may not be cost-effective. An epoxy or similar adhesive should be used to prevent the film from peeling off the cane. A potential spray adhesive to use is Camie 373 High Performance Adhesive, with a bond time of fifteen seconds to two minutes [**3**]. A fume hood and ventilation piping with appropriate personal protective equipment is recommended as a safety precaution for epoxy application, such as safety goggles, a respirator, and disposable gloves.

4.3 Reflective Aerosol Spray on White Paint

The paint and reflective aerosol spray can be applied with an automated spray machine, or by manual labor, each with their own tradeoffs. An automated method would require a much larger space and more expensive equipment than manually applying the coating. However, there is an increased health risk to the employee if the coating was applied manually. A fume hood and ventilation piping, with appropriate personal protection equipment, is recommended as a safety precaution for the spraying application. Such safety equipment would include safety goggles, a respirator, and disposable gloves. To decrease drying time of the paint, an appropriate sized conveyor belt oven can be used (Figure 25) [**4**].

Figure 25: Countertop oven used for curing

4.4 Powdered Glass Beads on White Paint

Like the reflective aerosol spray and paint (4.3), the powdered beads and glass can be applied manually, or with an automated spray machine. An automated method is recommended to increase the application consistency of the powder. Applying the powder manually would cause inconsistent coating thicknesses, possibly resulting in a lower than expected coating reflectivity. The powder is also extremely fine, which can pose a hazard to an employee’s respiratory system. A dust mask with an N95 rating, and safety goggles are suggested, especially if there is a high airflow in the application cell that could pick up and carry any powdered glass. An automated system could contain the powder, negating these health concerns. For any solvent-based paints, a fume hood and ventilation piping with appropriate personal protection equipment are also recommended as safety precautions. To decrease drying time of the paint, an appropriate sized conveyor belt oven can be used.

4.5 Standard Highway Glass Beads on White Paint

Like the other paint-based coatings (4.3 and 4.4), an automated application process is recommended. Even though the standard highway beads are larger in size than the powder, the beads are still small enough to be applied through a spray nozzle. One benefit of the larger glass beads is the decreased health risk, so safety equipment would not need to be as extravagant as if the powdered glass beads were being used. Again, an appropriate sized conveyor belt oven can be used to decrease the drying time of the paint.

4.6 Application Cell Summary

For the paint-based designs, an automated application cell is recommended, while the mirror film would best be applied manually (TABLE XV). The application cell for the reflective aerosol spray and white paint coating has the potential for a large cycle time, as the paint would have to dry before applying the reflective spray. However, using a curing oven to decrease the drying times would help minimize the impact on cycle time.

TABLE XV: APPLICATION CELL RECOMMENDATIONS SUMMARY

Recommended Application Cell	Implementation Cost	Work Space Required	Application Cycle Time
Mirror Film			
Roll dispenser with semi-automated epoxy application and ventilation system	Low	Low	Medium
Reflective Aerosol Spray on White Paint			
Automated paint application with ventilation system, and drying/curing oven	High	Medium	Medium
Powdered Glass Beads on White Paint			
Automated paint application with ventilation system, and drying/curing oven	High	Medium	Low
Standard Highway Glass Beads on White Paint			
Automated paint application with ventilation system, and drying/curing oven	High	Medium	Low

A more thorough analysis is required to determine precise effects for each cell, but is not within the scope of this report. Overall, our group recommends the mirror film, as its application cell is expected to have the lowest cost, smallest impact on workspace, and smallest impact on cycle time.

5 Conclusion

This project has been considered a success, as we have developed reflectivity and durability testing methods and procedures, determined four viable cane-coating alternatives, and provided recommendations as to application cells for those coatings. The testing methods and procedures were used to quantify the reflectivity and durability for each of the candidate materials, allowing us to score the designs and select the best coatings.

The mirror film outperformed the existing 3M tape in each design category of weight, reflectivity, durability, and cost. The mirror film was 16.08% more reflective, 2.53% more durable, 3.58% lighter, and $0.927 less expensive than a cane coated in 3M white reflective tape. The total material savings for manufacturing 75 000 canes per year is an estimated $69 525. We recommend that a Camie 373 high performance spray adhesive be used to bond the mirror film to the cane segments in order to prevent the mirror film from peeling off of the cane. For the application cell, a semi-automated dispenser that cuts the mirror film according to the desired lengths should be implemented. Rolling machines can be used to attach the mirror film onto the individual cane segments, and such machines are currently used in the AmbuTech manufacturing facility.

We also recommend that continued testing of material alternative be completed. Changing the type or brand of any of the materials we used could yield vastly different results. Continued testing could also lead to establishing industry standards, showing that AmbuTech is a world leader in mobility products.

References

[1] PlotDigitizer. (2013, Jun. 8). *Plot Digitizer* [Online]. Available: http://plotdigitizer.sourceforge.net [2013 Nov. 3].

[2] Cole Brothers. (2004, Sep. 20). *Standard Highway Safety Marking Spheres* [Online]. Available: http://www.colebrothers.com/glassbeads/glassbeads2.pdf [2013 Nov. 20]

[3] Camie-Campbell, Inc. *Camie 373 Product Data Sheet* [Online]. Available: theepoxysource.com/data%20sheets/CAMIE%20data%20sheets/373.pdf [2013 Nov. 20].

[4] Lincoln, *Countertop Impinger (CTI) – 1300, 2500, & V2500 Series* [Online]. Available: http://www.lincolnfp.com/products/cook-ovens/countertop/electric/countertop-impinger-(cti)-1300-2500-v2500-series [2013 Nov. 18].

Appendices

Appendix A: CdS Photoconductive Photocell PDV-P5002 Data Sheet

The Advanced Photonix, Inc. PDV-P5002 CdS Photoconductive Photocell was used in the reflective testing procedures. The photocells were instrumental in determining the reflectivity of various materials. The photocells are light dependent resistors, changing resistance depending on the amount of light striking the photocell. We determined the reflectivity of various materials shining a light onto the material, reading the corresponding cell resistance, and then determining the illuminance level from the cell resistance vs. illuminance provided on the datasheet.

[redacted]

Figure A 1: PDV-P5002 datasheet [1]

The PDV-P5002 datasheet contained vital information that allowed us to calculate the reflectivity of various material coatings. By reading the resistance of the photocell, we determined the illuminance reflected from the material, and then calculate how much light was reflected from the coating.

Appendix A References

[1] Advanced Photonix, Inc. (2006, Mar. 30) *CdS Photoconductive Photocells PDV-PDV-P5002* [Online]. Available: http://www.advancedphotonix.com/ap_products/pdfs/PDV-P5002.pdf [2013, Oct. 26]

Appendix B: Calculating the Equation of the PDV-P5002 Cell Resistance vs. Illuminance Line

PlotDigitizer, a freeware plot digitizer, was an instrumental tool in determining the equation of the PDV-P5002 cell resistance vs. illuminance line. By determining two points on the line, we were able to calculate the equation of the line. With the equation, we could calculate the illuminance of the light reflected from the test samples, and determine the coefficient of reflectivity of the coating materials.

	A	B	C	D	E
1	Resistance (Kohms)(Illuminance (lux)), created by Plot Digitizer, 2.6.3				
2	Date: 11/3/13, 8:05:50 PM				
3					
4					
5	2				
6	Illuminance (lux)	Resistance (Kohms)			
7	3.02715	42.6643			
8	49.9606	12.0731			
9					

Figure A 2: Screen capture of data points determined by PlotDigitizer

$$\log \Omega = A \log E + B$$

$$\log 49.96 = A \log 12.07 + B$$

$$\log 3.03 = A \log 42.66 + B$$

$$\log 49.96 - \log 3.03 = A(\log 12.07 - \log 42.66)$$

$$1.217 = -0.548A$$

$$A = -2.221$$

$$\log 3.03 = -2.221 \log 42.66 + B$$

$$B = 4.102$$

$$\log \Omega = -2.221 \log E + 4.102; [\Omega] = Kohms, [E] = lux$$

By using PlotDigitizer to determine two points on the cell resistance vs. illuminance line, we were able to calculate the equation of the line for the PDV-P5002 photocells. We then used the equation to calculate the illuminance of the light reflected from the test materials, and calculate the materials' coefficients of reflectivity.