University of Toronto
Faculty of Applied Science and Engineering
APS 112
Engineering Strategies and Practices
Final Design Specification

Project title	Team # 21
	The Human Bare Foot Sensor
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EXECUTIVE SUMMARY

Pedestrian falling accidents are the number one preventable loss type in the workplace and public areas (English, 2004). The cost of these accidents is second only to automobile accidents (Redfern et al. 2001). Walters Forensic Engineering Inc. has encountered a limitation on the use of the English XL Slip meter and our team proposes a solution to this limitation. The English XL Slip meter is used to test the slip resistance of floor surfaces. It employs a variety of different test pads that can be changed in order to represent different scenarios; however a pad has not yet been developed to represent a human barefoot. The design challenge that has been proposed is to find the best material to represent a barefoot walking on a wet surface. This situation involves an extensive amount of variables that would be very difficult to measure. For this reason it was realized that a device would be needed to directly compare a human foot to a material, in order to find the best representative material. This leads into the second design challenge, to design a device that can accurately compare a material's slip resistance properties to that of a human foot. A well-detailed description of the problem can be found in the Problem Definition section of this report.

There are many stakeholders involved in this design. Since the English XL is commonly used to test public walkways almost any citizen is a potential stakeholder in this design. A successful design could mean safer walkways around pools, showers, change rooms, and many other public places. The success of the design will be determined by the accuracy of the material found. To achieve this accuracy, the main functional requirement of the pad is to represent a human barefoot as closely as possible. In order to compare different designs several design parameters have been specified as objectives and constraints. The designs for the device as well as the pad must meet their objectives and perform well in their service environment. For further detail regarding these topics refer to the Background section of this report.

In order to find the representative material a device was fabricated to accurately compare a material to a human foot. Through testing with this device, potential materials were selected that best represent a foot, and from these materials a pad can be made. The design mainly consists of a slide that allows a foot or a material to slide down and impact a surface at a predetermined angle. By adjusting the angle of impact, the material that best represents a human barefoot may be found. Before deciding upon this design, several others were considered. Although each had its own advantages, it was determined that our current design would be the best choice. A detailed description of the design and all aspects involving it can be found in the Detailed Design and Implementation Requirements sections of the report.

The device will have a very short-term scope; however the pad's scope will be more extensive. After the device has been used by the team to find the most effective material it will be discarded. In contrast, the proposed pad will be cheap, simple and could be replicated by *anybody* who owns an English XL. The device and pad will be shared, not sold, so there are not many economic considerations to be made but the intended market for the pad is any owner of an English XL slip-meter. It is hoped that this pad will positively affect society by providing safer walkways around pools, showers, etc. There will be no negative effects on society or the environment as a result of this design, and in fact the worst possible outcome would be that it has no affect at all. The pad being designed will not infringe on any existing patents nor will it violate any of the regulation safety codes that pertain to the English XL. A more in-depth discussion of these topics can be found in the Market Issues, Regulations, and Life Cycle Issues sections.

This report discusses all the factors affecting the design of this pad as well as the effects that this design will have for our design team, Walters Forensic Inc., and society in general. Currently there is a strong lack of public safety as falls are the leading cause of accidental death in senior citizens (Redfern et al. 2001). Through our design we aim to improve the current levels of public safety and are confident that we will achieve this goal.

PROBLEM STATEMENT

Walters Forensic Engineering Inc. currently employs an English XL Slip meter in order to measure the slip resistance of walkway surfaces. This slip meter uses a variety of disks to simulate and test for different scenarios and conditions. However, the tester is currently unable to measure the slip resistance of a human barefoot on wet surfaces. The design team that will undertake this project is a group of first year undergraduate engineering students from the University of Toronto enrolled within the Engineering Strategies and Practices course (ESP). The ESP design team proposes to design a human barefoot sensor, fitted to the English XL that will emulate all aspects of a human footstep. The sensor will imitate characteristics such as the texture, friction, and rigidity of a human foot. By accurately imitating these characteristics the sensor could then be used as a precise and valid friction test. The main function of the design will be to represent the scenario of a human barefoot stepping on a wet surface, such as in showers, change rooms, pools, or even spills etc. This will enable one to test the slip resistance, and thus safety, of certain surface materials. The sensor material should be durable and withstand the abuse of the English XL slip tests to increase useful product-life. The material should also be water-resistant as its main function will be to test wet surface conditions. As well the sensor's production cost shall be under $200.

It has been found through research that the human foot does not follow conventional notions of friction during a footstep. In actuality the situation involves a combination of both kinetic and static friction (Taylor and Francis Ltd. 2001). For this reason, simple friction slide-tests and calculations would be inaccurate in measuring the slip resistance of a human foot. Thus, the ESP team will also design a device in order to accurately compare a material's slip resistance to that of a human foot under walking conditions. The device should incorporate a degree of testing variability so as to be able to test different surfaces, materials, and also heel impact angles. The device should allow for repeated testing of different materials to ensure reliability and validity. Since human feet will be needed to conduct the testing, safety shall be a priority and subjects involved in the testing shall not be harmed. This device shall ultimately be employed to test a variety of materials in order to provide the client with a list of 6-12 materials that best represent a human foot in all aspects. This will be accomplished after thorough testing and research of different materials.

The results of the human barefoot sensor design project shall be presented to Walters Forensic Engineering Inc. on April 26, 2004.

BACKGROUND

STAKEHOLDERS

Walters Forensic Engineering Inc.

- A sensor for bare feet testing on wet floors will make their test results more trustworthy in court and attract more clients.
- They will also be able to author and publish another scientific paper.

Mr. William English (designer of the English XL)

- Adding a sensor for a human barefoot to his English XL would make his product the best on the market for checking slip resistance between any two surfaces, even bare skin.

The General Public

- The bare foot sensor would improve public safety on wet surfaces where people walk bare foot.

English XL customers

- Companies that use the English XL can now add the bare foot sensor and employ it in their machines allowing them to test wet surfaces for safety.

Functional Requirements

The functional requirements of the human barefoot sensor are as follows:

- To test the slip resistance of a human barefoot on any surface.
- Be designed to fit onto an English XL Slip meter so that the user may perform standard slip tests.
- Accurately replicate a human barefoot in texture, friction and also impact properties.
- Even though it should work on any surface, the sensor will be specifically designed for the testing on wet surfaces (decks, pool tiles, etc…).
- The sensor material will simulate the properties of a human foot accurately enough so as to be valid for its main function in court.
- By emulating the slip resistance of a barefoot, the proposed sensor will evaluate the safety factor of any surface materials in question.

The ESP team will design a device capable of confirming the validity of a material's behaviour and structure as similar to human skin, in order to find a material that holds the same properties. For this apparatus, the major requirement will be to prove that a certain material functions the same way as a common barefoot. This device, on its own, may well be used for purposes other than this project. The device designed will be capable of accurately testing the properties of two materials against each other, thus this device will be able to compare any two materials together (not just human skin).

The English XL Slip meter generates an accurate depiction of a human step, and the impact that is placed onto a surface is very similar to a real human foot. As a result, the proposed barefoot sensor will also be capable of testing other properties of surfaces. The slip meter, with our design, can be used to test the strength of flooring, walls, or any other surface that a human barefoot may come in to contact with. Also, the durability and lifetime of a surface may be tested by repeatedly and continually applying the slip meter to a material.

Objectives

- The product should be a representation of reaction of human bare-foot skin upon impact. The product's main purpose is to test whether or not a certain surface would be slippery when bare footed pedestrians walk on it.
- Should be durable and particularly testable on wet surfaces such as pool-sides and bath tubs. Slip incidents of interest in this project are those occurring on wet surfaces, where the foot strikes down. Furthermore, portability is fairly pursued.
- Should be used primarily in conjunction with the English XL slip meter, along with other test devices if necessary. The materials should be attachable (and so to a known type of screw) to the English XL in order to test its slipperiness when striking a certain wet test surface.

- The design should give reasonably accurate observations on how a bare foot would react to wet surfaces when the heel strikes that surface. That is, the material to be employed should behave towards wet surfaces as human heel skin would.

CONSTRAINTS

- The product shall be safe, particularly to the tester (user). To emphasize, the product shall be made with non-hazardous materials. Safety is an important consideration that the client would normally pursue.
- Shall be test-able mainly on smooth tiles, textured tiles, and concrete. Those types of surfaces were primarily suggested by the client as test subjects.
- Shall be readily available, i.e. found in the market, and not made, for example, in a laboratory particularly for this task. This would be more convenient than 'making' a material, however this may mean that the required functions may not be 'perfect'.
- Shall not be very costly. The product shall be readily accessible to users and also cheap and affordable.

SERVICE ENVIRONMENT

Each of the two design challenges will encounter different service environments. The first being the barefoot material tester used to find an imitation "human skin" material. This material tester will encounter a very specific service environment as it will be used only by the design team and the client, and only for a short period of time. As it will be used primarily by the design team, the material tester will not experience any abuse or misuse, and the users will understand how to operate it. The conditions for the material tester's use will be controlled. It will be used indoor and on level ground in order to maintain accuracy. The tester will be exposed to water, and may be exposed to corrosive liquids. During its use it may have to support the weight of an adult during a footstep. It will be subjected to very repetitive use for a period of time. Although the material tester will encounter some minor dirt/dust, the amount would be minimal and it would be kept clean. Since it will come into contact with a human barefoot, proper sanitization will be required after every use. The device will be safe for its operators and especially the test subjects, since subjects outside the design team may be called upon for testing. It will not have to be aesthetically pleasing as it is only used as a test device, it will not be reproduced or marketed.

The second design, the human barefoot sensor (slip-disk) will encounter a very different environment. The sensor will be mounted on an English XL Slip meter and thus will have to fit all necessary dimensions and specifications. It will encounter indoor and outdoor use, and be subjected to a variety of contaminants. Since it will be used all year round it may be used in a variety of temperatures, it must remain accurate in every temperature. Since the unit will be testing many different circumstances the sensor may come in contact with oils, soaps, commonly used liquids, pop, water, and any other substance on a floor. It will also come in contact with dirt, sand, pebbles and other small debris that may be lying on the floor during the testing. Since the sensor may encounter these contaminants, it should not be affected by their presence. The sensor will impact the ground at a force resembling a human step. The sensor will be used by a variety of people, so it should be easy to mount on the English XL Slip meter. The sensor may be exposed to some user abuse if the slip meter is misused however.

CLIENT ETHICS AND VALUES

The client, Walters Forensic Engineering Inc., currently offers product liability, failure analysis, metallurgy and material science litigation support and many other safety related issues. Since the client is safety orientated, safety has to be reflected in the design project and should be made a high priority to ensure that the design does not pose a threat to the user. The design project's function is to make everyday environments safer by providing a material for testing the slip resistance of a human foot on different wet surfaces. So the main function of the design is to make floors safer for people.

One of the services that Walters Forensic provides is litigation support with years of courtroom experience. In order for the client to give strong testimony in court they need precise and reliable testing equipment. Therefore the material of the human barefoot sensor shall be well calibrated and shall accurately mimic the properties of human skin on wet surfaces to ensure that a strong testimony is given in court.

DETAIL DESIGN

ECONOMIC DECISION MAKING

The final design for the test device was proposed initially by the client, and was fairly easy to build, yet considerable time was still devoted to its design and manufacture. The design only called for common and inexpensive materials, which meant that the cost of building the device was fairly low. The only materials needed to be purchased (and put together) were a PVC pipe, some plywood, and for assembly, a framework of metallic links, screws, and brackets.

DETAILED DESIGN AND PROPOSED IMPLEMENTATION PROCEDURE

The design can be seen in **Figure 5.1 below**, it consists of a PVC pipe cut in half to act as a slide, and a metal frame network which provides support for the slide and allows the angle of the slide to be adjusted. By rotating the threaded rod that travels through the center of the device the angle of the slide can be increased or decreased. Starting at a fairly steep angle a human test subject will slide their foot down the slide allowing it to impact the ground. On the ground will be a wet tile (various types of tiles being tested) and whether the foot slips or not on the tile will be recorded. The angle of impact will gradually be decreased until the foot slips upon impact. At this point the slip angle for that type of tile will be recorded and the process will begin again with another type of tile. Approximately five tiles will be tested and the slip angle for each will have to be found. The tiles will be ranked in order of their slipperiness. This entire process will again be repeated for different test subjects representing a variety of different ages and sizes. After all the data has been collected testing will begin on different materials, following the same process. The goal is to find a material that will rank the five tiles in the same order that the human foot did. The material that is found to best represent a human foot on a wet tile will then be cut out and placed on a pad so that it can be used for an English XL Slip-meter. In addition, another very simple PVC pipe was made to allow the attachment of the different materials, as pads. The device can be seen in **Figure 5.2 below**. The PVC pipe would then be made to strike the tile by moving it manually along the larger diameter PVC pipe. *(refer to Appendix A for "Alternative Designs" and Appendix B for "Decision Making")*

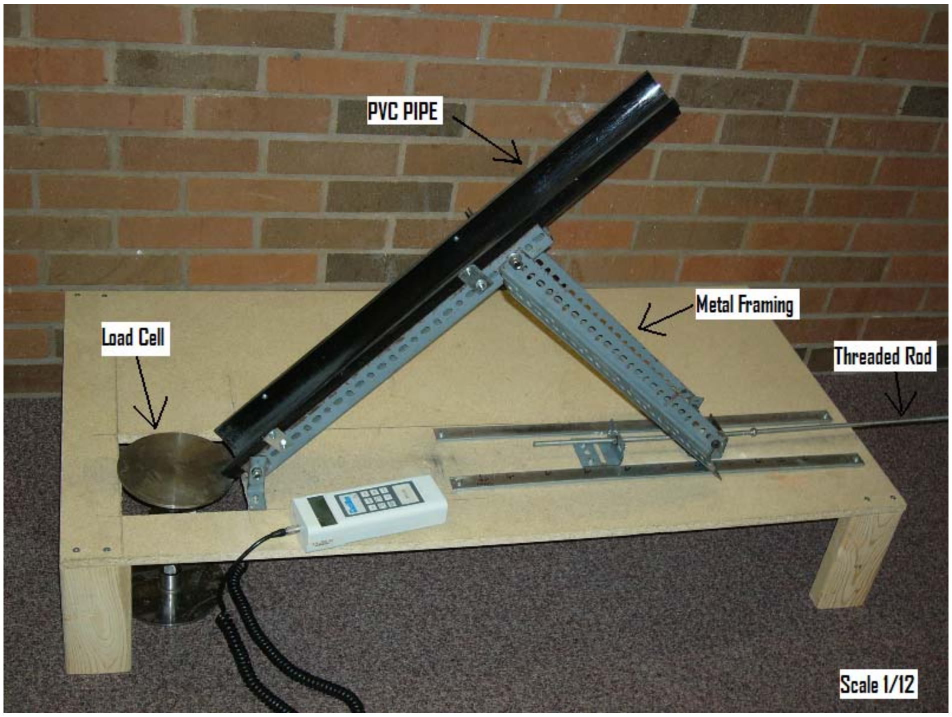

Figure 5.1

Figure 5.2

TESTING

Venue: Wilson Hall, New College, at the University of Toronto.
Surroundings: well-ventilated, non-humid, room temperature.

Tile testing: As proposed, the barefoot (tile) testing was done all at once and results enough to rate the tiles in order of slipperiness were achieved. Different genders, ages, heights, and weights were ‘employed’, so as to allow for variance and to check that results turn out to be *relatively* consistent. An allowable range of impact force was put forward by the team, according to a brief analysis of average weight (US FDA, 2005; Halls, 2003). After our testing we found that the tiles were ranked in this order from least to most slippery: 1. Vinyl Composite Tile (below 40º), 2. Marble (approx. 45º), 3. Smooth glossy finish (approx. 46º), 4. Textured Matte finish (approx. 47º), 5. Orange Peel finish (approx. 60º). The angles that follow the type of tile are the “critical angle” which is approximately the angle where slipping will begin to occur more often than not.

Material testing: Also as proposed earlier, the material testing stage was done all at once. The data collected was enough to reject or accept the possible representative materials of a human barefoot slipping on wet surfaces. Of the proposed materials brought together by the team members (about 15 - dependent on a bit of research or as suggested by the client), four were considered ‘passing’ (as of May 31st, 2005). These materials were classified as possible materials since the results of their slippage would rate the tiles in the same order as a human barefoot would.

After the material testing the four materials that rated the tiles in the same order were: a synthetic leather material, a rubber damping strip, a small toy basketball, and lastly a “Nerf” style foam. Each of these materials, according to the testing, have similar slip resistance properties to that of a human foot. Thus, these materials may be used when attempting to replicate a human barefoot impacting a wet surface during a step. However further testing would be required to find the associated factor that each material would need to exactly match that of a human foot (ie. Foam will slip at exactly 90% of the angle that a human foot would slip at). **Overall the "Nerf" style foam appears to be the best representative material for a human barefoot.**

SAFETY

Turning to safety considerations, the following point out how a safe final design was arrived at:

- The test device design had no sharp ends that could pose a hazard during testing.
- Stainless steel was used instead of normal steel, which does not corrode and so can in no way be poisonous. In fact, none of the parts were made of chemically hazardous materials.
- Despite the fact that the tiles were tested while wet, there were no injuries, not even minor, to any of the subjects during the testing stage.
- The test device design itself is a bit heavy, but is made to stay stationary throughout the testing implementation, therefore not causing any harm.
- All the parts of the design were made in such a way that allows for manually moving them. In case of an emergency, say a person's hand gets unintentionally stuck between links, the pipe can be lowered manually to increase the angle and free the hand.

DELIVERABLES TO CLIENT

- The whole assembly of the final main test device design (prototype).
- The auxiliary PVC pipe (prototype).
- 'Passing' materials, with information on where to find them and possibly details of their structure.
- Final testing recordings.

REGULATIONS, STANDARDS, SAFETY AND INTELLECTUAL PROPERTY

Since the proposed barefoot slip-sensor is designed for use on the English XL slip-meter, the safety regulations that apply to the slip-sensor would be the same regulations that encompass the English XL. The 3 pertinent safety standards to be adhered are the F1679-02 *test method for using a Variable Incidence Tribometer* (English XL 2004), the NFPA 1901 *standard for automotive apparatus*, and the OSHA 1962.754, (c), 3 standard (English XL 2004). The first involves the standard for conducting slip-testing using the English XL (ASTM 2005). The second standard refers to the fire regulations for automotive apparatus which applies to the pressurized CO_2 canister used by the slip-meter (NFPA). The last standard applies to the procedure of slip-testing on steel (US department of Labor 2003). Since these standards mainly apply to the English XL device itself or the user's procedure, the proposed barefoot slip-sensor will adhere to these codes simply because no industry standards apply specifically to the slip-sensor pads of the English XL. Aside from industry regulations and standards, other safety issues of this design have been considered and discussed in previous sections of this document. Specifically, the objectives, constraints, and service environment sections detail the safety issues of the barefoot slip-sensor in greater depth.

Along with safety regulations, the design of this product must take some intellectual property into consideration as well. The barefoot slip-sensor is designed specifically for the English XL slip-meter which is a patented product of William English's. However, the design is merely an addition to the existing slip-meter and there is no intention of marketing or reproducing the slip-meter. The design project was to investigate possible materials that mimic the human foot during slip-testing and thus does not infringe upon the patent and claim rights of the English XL slip-meter itself.

One patent issue that should be considered is the patentability of the test procedure and test device used to find the acceptable barefoot mimicking materials. Both the test procedure and test device that were designed to compare the slip properties of different materials to human feet appear to be originally invented. Preliminary research reveals that no other such tests exist or have been conducted, but more research into existing test procedure patents is necessary to confirm this. But the test procedure and device do appear to follow the criteria for creating a utility patent though, being useful, unobvious, and possibly unique and original.

If this barefoot slip-sensor design is to be implemented, it will adhere to applicable safety regulations and will not infringe upon legal patents or claims.

MARKET ISSUES

The final design of the bare foot sensor will not be mass produced and therefore will not be sold. However this human barefoot sensor is an improvement to the English XL and the users of the slip meter are the market for the sensor. Currently there are no other sensors that test the slipperiness of human bare foot skin on wet surfaces and no patents on the testing procedure along with the testing device.

The sensor is designed for the English XL (slip meter) which currently does not have a sensor for human skin and our product will be an addition to the list of sensors.

The product will be presented to William English (designer of the English XL) and if he approves the materials, instructions will be provided to English XL users describing the bare foot sensor material requirements.

IMPLEMENTATION REQUIREMENTS

In order to implement the proposed design, some crucial points should be taken into account. Initially, six test subjects were required to test their (wet) heels for slipperiness. To allow for variance, different genders and ages were tested, and so team members, females, and the elderly were used as test subjects. These subjects tested different test surfaces to obtain a control for the friction of human feet on these surfaces. Two sample blocks of surface material were borrowed from the client for the team's reference and testing. Other test surfaces were acquired from select hardware stores. Readings directly related to slipperiness and forces of impact were necessary to measure the friction from the experimentation. For this, the team used a variable load cell (that measures impact force) and a gravity-based protractor (that measures the angle of inclination) during the experimentation, both of which the client had provided.

Later in the process, the possible slip sensor test materials (barefoot sensor materials) will be implemented, where other readings (in this case 'slip/no slip' determination for different angles) will also be taken. This would now account for material slipperiness and deviation from human heel skin characteristics. At the start of the testing stages, the ESP design team might find it useful if the design was tested under client supervision. Therefore, the team would then need to use some of the client's test spaces and devices. During the testing stages, when human heel testing is completed and material testing has begun, the team might again find client supervision quite beneficial.

Considering skills required: the handling of the design and testing was very time consuming yet easy and manageable. Team members need not be trained, skillful, or experienced!

With regard to cost, the ESP design team needed only to buy different tiles and test materials for testing. The team needed to obtain small tools that help in handling, cleaning, etc. (such as wrenches, screwdrivers, towels, liquids, etc.) but some members had these tools so there was no need to purchase new ones. These costs would be minimal and remain under the $200 budget constraint.

LIFE - CYCLE ISSUES

Please refer to Appendix C for Life Cycle Diagram

The testing device is a strong build, robust device that is reliable and remains sturdy after hundreds of testing procedures using human bare feet and experimental material. It is made with all common materials, with excellent test variability options. There is not much that needs to be done in order to maintain this device. All moving parts of this device could be oiled for smoothness, but this will not be necessary in its short life. If any part of this device needs repairing, it can easily be replaced as no part is permanently attached to another.

At the end of its life many other parts of this apparatus could also be used again after the testing period comes to an end. Since the wood used in the design would not be cut into any irregular shape, it could easily be removed and used for other purposes. Since there will only be one single device constructed, there is no need to worry about loss of wood over a long period of time. Along with the proposed friction test design, some previously existing tools would also be used in correlation with the design during the material friction testing. The tool used to measure the inclination angle of the test surface is an existing inclination meter, and would be fitted onto the test device with minor adjustments. Furthermore, the device for measuring the force of an object striking the test surface is also a previously existing tool to be adapted to the design. This can, and will, be reused when the friction testing with the apparatus is complete.

The testing device design will cost the client only the materials used in manufacturing it, some additional testing devices are provided by the client and the money used is part of the project's $200 budget. However there are no labour or distribution expenses because it is a simple design and there is only one being built by the students.

The actual slip-sensor pad itself will be attached on top of a sturdy aluminum piece, which is designed to withstand the testing procedure (impacting surfaces) during testing. When implemented on the English XL the pad will be glued on strong to an aluminum disk, which is easily installed onto the slip meter. When the pad material has been used till the end of its useful lifecycle it can then be disposed of easily and cleanly.

This final slip-sensor design (the slip pad) will not be mass-produced and the current owners of English XL's will only require an aluminum disk to attach the pad material to employ it. Since the material that will be used for the sensor must be a common material it will be affordable and easily acquired. The owners of the English XL will be able to manufacture their own sensor by just attaching the material on top of an aluminum disk. This will mean that our client will not have to allocate any further funding.

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APPENDIX A
ALTERNATIVES & CHOSEN DESIGN

ALTERNATIVE DESIGN 1 *(MAHMOUD'S)*

The first solution is a rigid panel fixed on a rigid spring, which in turn is driven by a motor or hydraulic press. The panel is to raise a certain height, and strike the heel on the way. Refer to Appendix A (Figure 1.1, 1.2, 1.3) for a detailed description and for clarifying drawings. Advantages include the ability to determine the velocity of impact as a motor is used. Also, most importantly, human reflex is eliminated as the test subject wouldn't 'feel' that he or she is being tested on, and wouldn't jerk their foot (tighten the knee cap), as would be the case if the test subject were made to simply walk on a slippery surface (where they know they could slip at some point). As a consequence, the distance the heel slips would be quite reasonable and accurate. Furthermore, the angle of the test surface could be changed and varied fairly easily to test different situations and impact angles. Finally, disadvantages include that such a design would be expensive to build and difficult to implement. Also, the team anticipates such building of a design to be time consuming, and for purposes of the client need, such accuracy, if obtained at all, is not of significant importance.

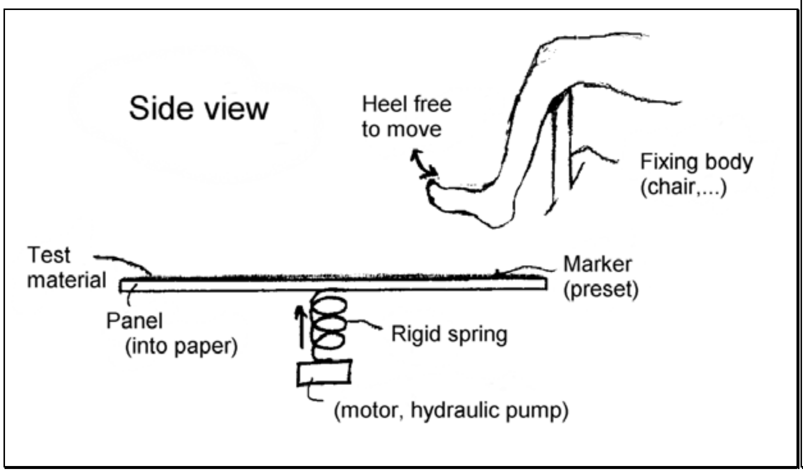

Figure 1.1

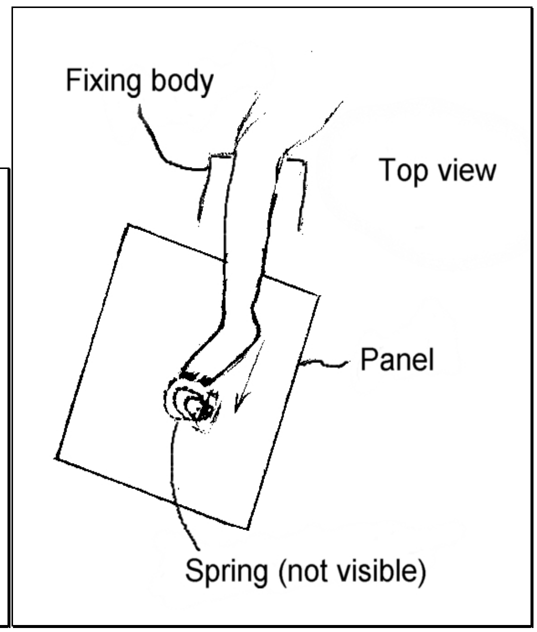

Figure1.2

First of all, note that the test subject's knee is to be fixed, say for instance on a chair-top, above the apparatus of the design. This should leave his heel (wet) in the air, free to move and not touching anything. The design consists of a rigid rectangular panel that is fixed atop a rigid spring, the panel being described in the horizontal plane. The spring would, say, by a motor, move the panel upwards towards the heel. The design would be made in such a way that the angle between the spring and the panel is always 90 degrees (any fixed angle would do, but this is easiest to deal with). Basically, the spring should be connected very stiffly to the panel's centre, at right angles to it. To allow for variance, the angle of *impact* with the heel can be changed by fixing the motor base on an incline. As the panel strikes the heel, the heel would slip (if any is to happen) in the forward direction. The panel would be made to rise to a known distance. Furthermore, this panel can be coated with the test materials (or the materials just 'glued' unto it), to test for their slipperiness.

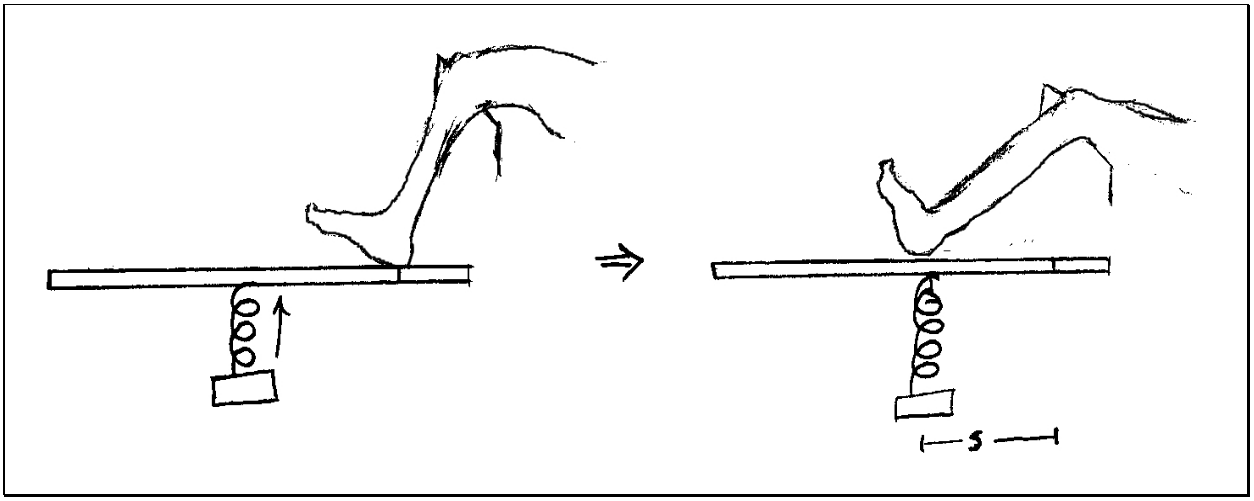

Figure 1.3

<u>ALTERNATIVE DESIGN 2 *(NICK'S)*</u>

The first step in our project was to design a device that would allow us to directly compare the slip resistance of a human foot to that of a material. One of the designs that was considered, (Figure 2.1, 2.2, 2.3 and 2.4 – Appendix A), has a tray on wheels that is under a horizontal force. The frame around the tray is opposing this force initially but once a foot provides a force downward the tray will fall beneath the frame's support and will want to slide backwards. Only the friction between the human foot and the tray will stop it from slipping. Materials could be tested by attaching the material to a shoe. One advantage to this design is that it allows for variability. The horizontal force could easily be increased or decreased, the length of slip could be measured, different tiles could be placed on the tray, and it could easily be used by test subjects of all ages and sizes.

However there were several drawbacks that led to deciding against it, one of which is its questionable accuracy. Since the user must step down on the tray, it may result in inaccurate data because the user could step down at a different rate each time. This would allow the tray to have an initial velocity, and thus it would take longer for friction to stop it giving us inaccurate slip data. As well as this lack of accuracy, we were unsure of the design's durability due to its number moving parts. The design seemed complicated enough to question if all the moving parts would stand up to the repetitive testing. For these reasons it was decided that another design would provide a better solution.

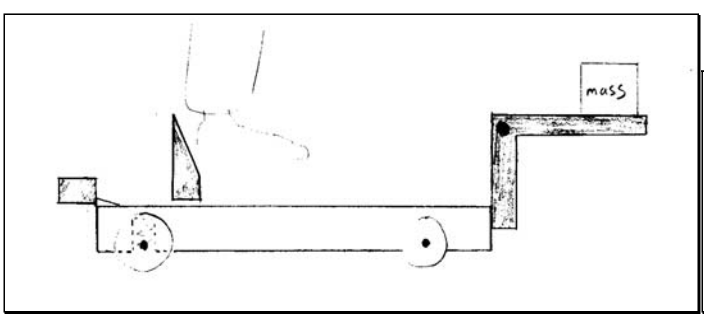

Figure 2.1

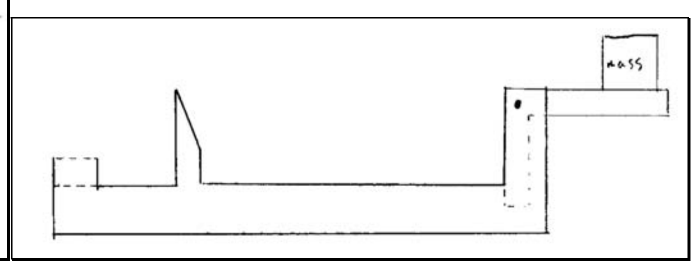

Figure 2.2

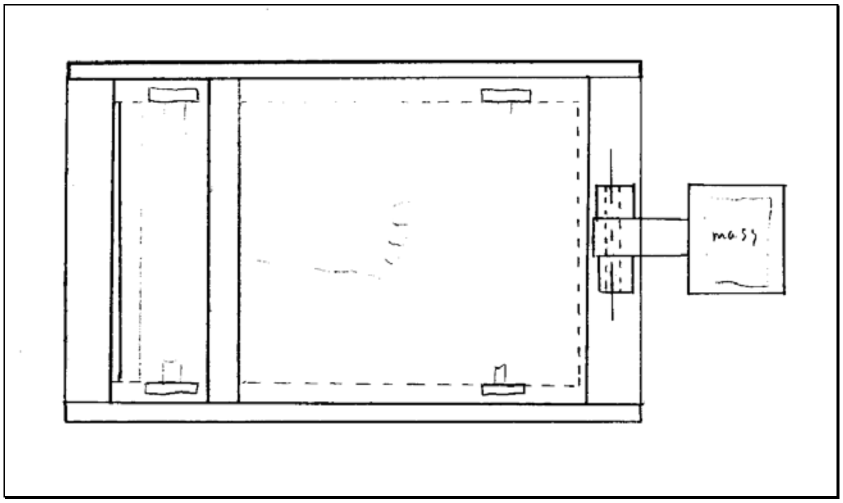

Figure 2.3

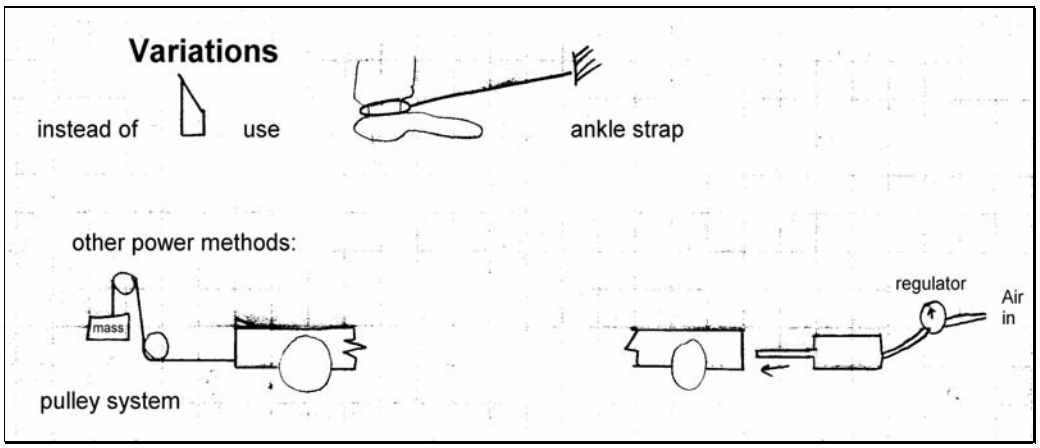

Figure 2.4

The cart in the center of the frame is on wheels and can roll independent of the frame around it. At the front of the frame the weights provide a horizontal force on the cart pushing it toward the back of the frame. This motion is stopped by the frame since at the back of the cart there is a lip witch is pushing up against the frame. The frame restricts the cart from moving backwards but the weights cause gravitational potential energy to be stored, waiting to be released. The test subject will slide their foot along the small ramp attached to the frame and allow their foot to step on the cart as if it were the ground. The force of the foot on the cart will compress the suspension at the rear of the cart, dropping its height by a set distance which then allows the lip to slide past the frame (caused by the horizontal force at the front). At this point the only thing stopping the cart from moving backward is the frictional force between the foot and the cart. If this force is great enough the cart will not move, if this force is not, the cart will slide past the foot and this would represent a slip.

ALTERNATIVE DESIGN 3 *(CHIN'S)*

Another alternative solution generated for comparing the slip resistance of different materials to the human barefoot is shown and explained in Appendix A (Figure 3.1). One major advantage of this alternative is that the force with which the subject's foot contacts the test surface is kept constant and can be calculated. This is due to the subject's foot being restrained and held still, as opposed to traditional friction tests that require the subject to step down onto a surface thus applying varying amounts of force. This increases the accuracy and repeatability of the friction tests for this particular alternative. Another advantage is that the different test surfaces may be employed on the end of the hinged stand easily enough. There were several large disadvantages with this alternative however. The first being that the friction being tested in this case is dynamic friction since the test surface must drop and strike the subject's foot. This is a problem because it has been shown that in actuality the impact of a human step involves both static and dynamic friction. Secondly, to build this apparatus would be quite costly, and also would take a bit of time to build. Also, it would be hard to wet the test surfaces since they are suspended in the air and held vertically before being dropped. Lastly, it would be difficult to test different impact angles of the subject's foot upon the test surface when it is dropped, thus limiting the variability of the testing that this alternative could perform.

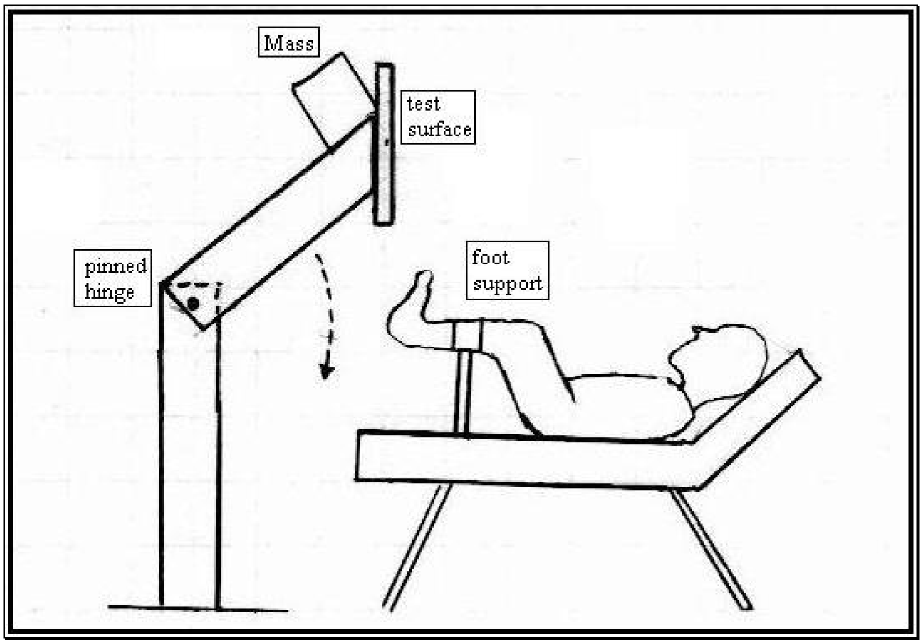

Figure 3.1

The following is another alternative solution created for comparing the slip resistance of different materials to the human barefoot. This alternative has a person lying down with their foot restrained and held in the air, where a hinged stand is dropped and swung down at the subject's foot. On the end of the hinged stand is where the different test surfaces may be placed so as to strike the subject's foot as it is dropping. There is a known mass attached to the stand so that the velocity of the dropping stand may be calculated. Then by measuring the distance that the subject's foot slips on the surface before stopping, the friction between the test surface and a human foot may be calculated using kinetic equations. These obtained values can then be compared to that of the different bare foot sensor materials to find a close match for a material that imitates human skin.

ALTERNATIVE DESIGN 4 *(CRISTIAN'S)*

Our final alternative considered has the floor tile inclined while the person steps perpendicular to the ground and the testing materials are also perpendicular to the ground. Refer to Figure 4.1 and 4.2 in Appendix A for details on this design. The floor tiles can be set on a rectangular frame (#1 in Figure 4.1) that can be adjusted at angles that are multiples of five. The pipe (#2 in Figure 4.1) can be interchanged between a half pipe so that a human can guide its heel for an accurate strike at the chosen angle and a full pipe through which the material is released in order to accelerate to the desired velocity so that the energy is the right amount of force the impact of the heel has on the ground while walking. The weight will be restricted to operate only inside the pipe and will not fall out to prevent breaking the tile. The pipe can also be adjusted to different heights. Underneath the tile there will be enough space for a load cell to fit in order to measure the impact of the heel and of the material making sure the impact force is similar every test and if it isn't the test will be repeated.

The advantage of this device is that it is easier to get the impact force to be similar each time because it relies on gravity. The gravitational field does not change and the difference in mass of the test materials is negligible therefore, if released from the same height there will be no change in the impact force.

The disadvantages are that in order to get a wet surface a constant flow of water is needed from the top of the tile. Accuracy of results decreases because the degrees of inclination are increased or decreased by five degrees.

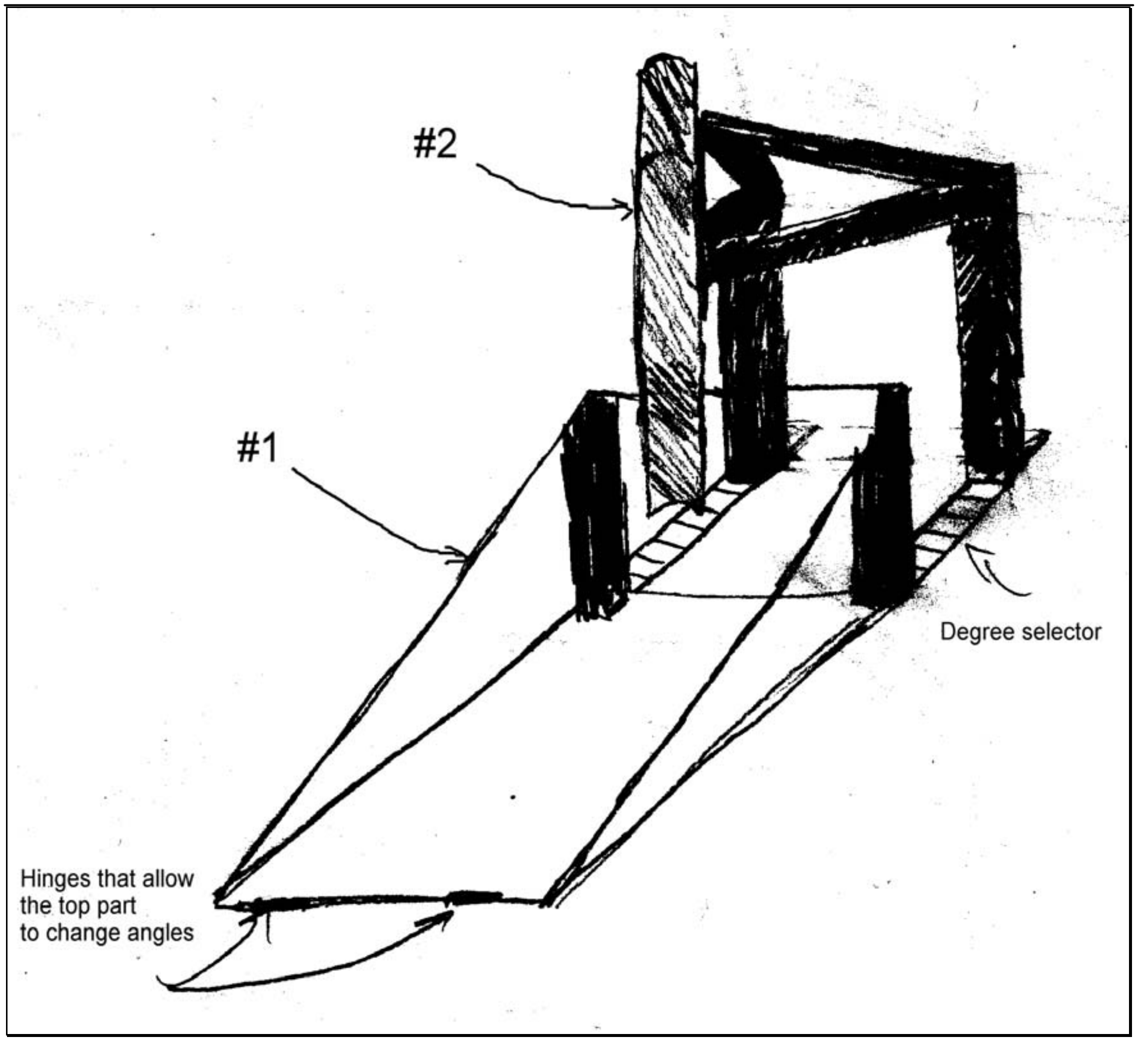

Figure 4.1

This design tries to keep the foot perpendicular to the ground because it's a more natural position. The user slides his foot on the divided PVC pipe and impacting the tile with the same force that would be applied when walking. The angle of the tile can be changed by 5 degrees. After the tiles are ranked using the human skin the PVC pipe is changed with a full pipe in which a cylindrical weight is placed and accelerates the material pad to the desired velocity. Following the testing the tiles are ranked accordingly.

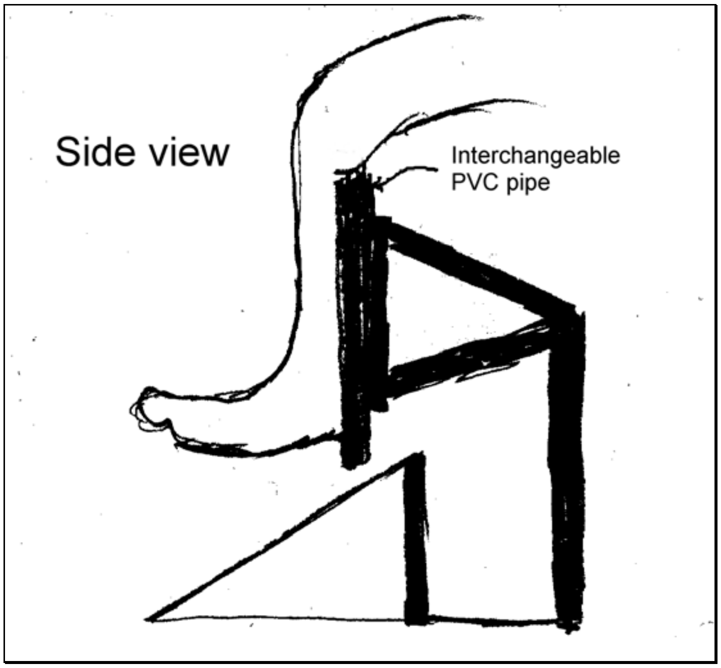

Figure 4.2

CHOSEN DESIGN

The design we chose for the device was that of Walters Forensic. This design maximizes our set objectives and does not violate any constraints. The decision process is explained in Appendix B (Table1.1, 1.2, 1.3) but briefly, we used a pair wise comparison and a morphological chart. The design can be seen in Figure 5.1 and 5.2 in Appendix A, it consists of a PVC pipe cut in half to act as a slide, and a metal frame network which provides support for the slide and allows the angle of the slide to be adjusted. By rotating the threaded rod that travels through the center of the device the angle of the slide can be increased or decreased. Starting at a fairly steep angle a human test subject will slide their foot down the slide allowing it to impact the ground. On the ground there will be a wet tile (we will be testing various types of tiles) and we will be recording whether the foot slips or not. The angle of impact will gradually be decreased until the foot slips upon impact. At this point the slip angle for that type of tile will be recorded and the process will begin again with another type of tile. Approximately five tiles will be tested and the slip angle for each will have to be found. The tiles will be ranked in order of their slipperiness, after what critical angle slip begins to occur. The steeper the required critical angle, the more slippery the material is. After the tiles have been ranked we will find a material that ranks the tiles in the same order and this will be a material that represents a human barefoot. The material found will then be cut out and placed on a pad so that it can be used for an English XL Slip-meter.

Figure 5.1

Figure 5.2

Since the device will undergo extensive testing trials it was built sturdy and durable, and to remain accurate. The main features that this design employs are its variability, its high durability, and the fact that it was relatively easy to build. The variability of this design is evident through its aptitude to easily change impact surfaces (different tiles), to change the angle of impact and to allow an easy conversion to test materials. The design is durable because its frame is metal and its parts do not move during testing. Almost every other design involved parts that moved during a test, and this could prove to be a problem after 500 tests have been performed. However, one downside to the design is its possible inaccuracies. Since the human foot must be slid down the slide to impact the ground, it is likely that there will be variations in the impact speed as well as the force. Although accuracy is important it was determined that for our budget, and to meet our time constraints, this design was the best solution. As well there are possible solutions to the problem of inaccuracy. To ensure consistency between tests a load cell may be employed to measure the impact force at the bottom of the device. This will allow us to achieve more accurate data throughout our testing.

Figure 5.3

Figure 5.4

APPENDIX B
ALTERNATIVE VALUATION & DECISION MAKING

This appendix contains the evaluation processes of the friction test device alternatives, and the final conceptual design decision reached.

Based on the results of the pair wise comparison, the objectives are weighted accordingly for the morphological chart. Using the morphological chart, it can be seen that the best design to use will be the one provided by Walters Forensics Inc. It meets all the constraint requirements, and scores the highest in the objectives. Mahmoud's design as well as Chin's design cannot be considered for their objective percentages because they do not meet the constraint requirements.

	Accuracy	Ease of Build	Durability	Test variability	Total
Accuracy	✕	1	1	1	3
Ease of Build	0	✕	1	1	2
Durability	0	0	✕	0	0
Test Variability	0	0	1	✕	1

Table 1.1

The pair wise comparison of the 4 major objectives of the friction test device that was conducted. Each objective is weighed against each other one at a time, and the total points of each indicate the obtained importance of the objective (3 being the most, 0 being the least important).

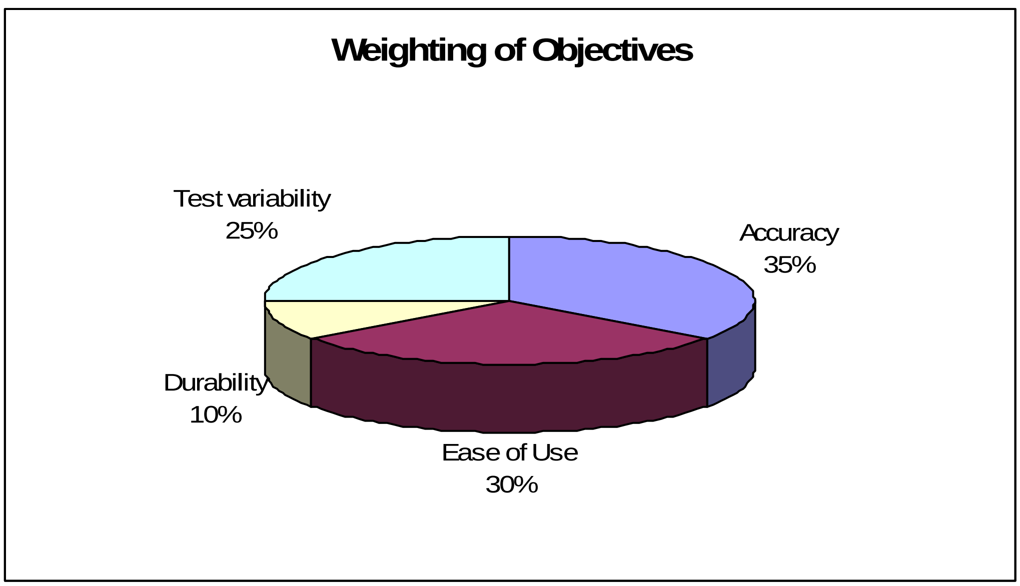

Table 1.2

Based on its importance (obtained through the pair wise comparison) each objective was allotted a specific weighting percentage denoting its value.

MORPHOLOGICAL CHART

		MEANS				
		Mahmoud	**Nick**	**Chin**	**Cris**	**Walters**
OBJECTIVES	**Accuracy**	0.35(0.9) **=0.32**	0.35(0.7) **=0.25**	0.35(0.8) **=0.28**	0.35(0.65) **=0.23**	0.35(0.60) **=0.21**
	Ease of Use	0.30(0.5) **=0.15**	0.30(0.8) **=0.24**	0.30(0.6) **=0.18**	0.30(0.8) **=0.24**	0.30(0.9) **=0.27**
	Durability	0.10(0.7) **=0.07**	0.10(0.7) **=0.07**	0.10(0.7) **=0.07**	0.10(0.8) **=0.08**	0.10(0.9) **=0.09**
	Test Variability	0.25(1.0) **=0.25**	0.25(0.9) **=0.23**	0.25(0.9) **=0.23**	0.25(0.8) **=0.20**	0.25(1.0) **=0.25**
CONSTRAINTS	**Safety**	√	√	√	√	√
	Time to Build	✕	√	√	√	√
	Cost	✕	√	✕	√	√
	TOTAL	78.5%	**78.0%**	75.5%	**74.8%**	**82.0%**

*options that do not meet constraint requirements cannot be considered.

Table 1.3

The morphological comparison of the 5 different alternative designs for the friction testing device. For each alternative, the design objectives and constraints were examined and rated on a scale of 1 to 10 (10 being the best). Next, the rating was multiplied by the percentage weighting of each objective (obtained in fig. 2), and the scores were added up to give the total value of each alternative.

APPENDIX C
LIFE CYCLE

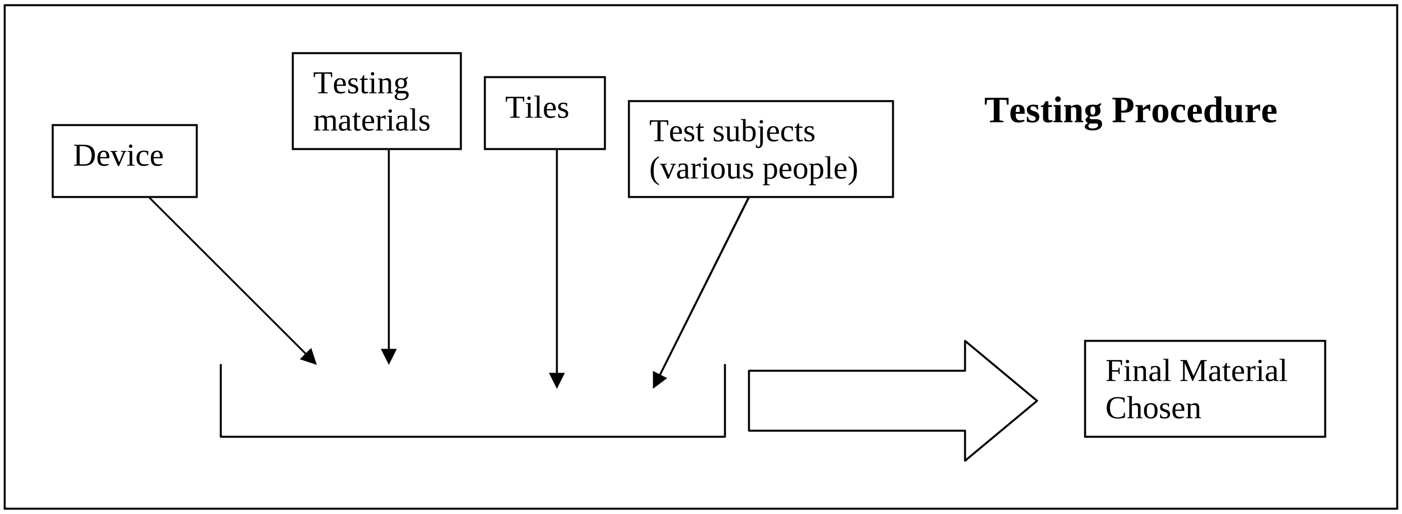

Figure 6.1

The overall view of the project showing what is required to reach the final product.

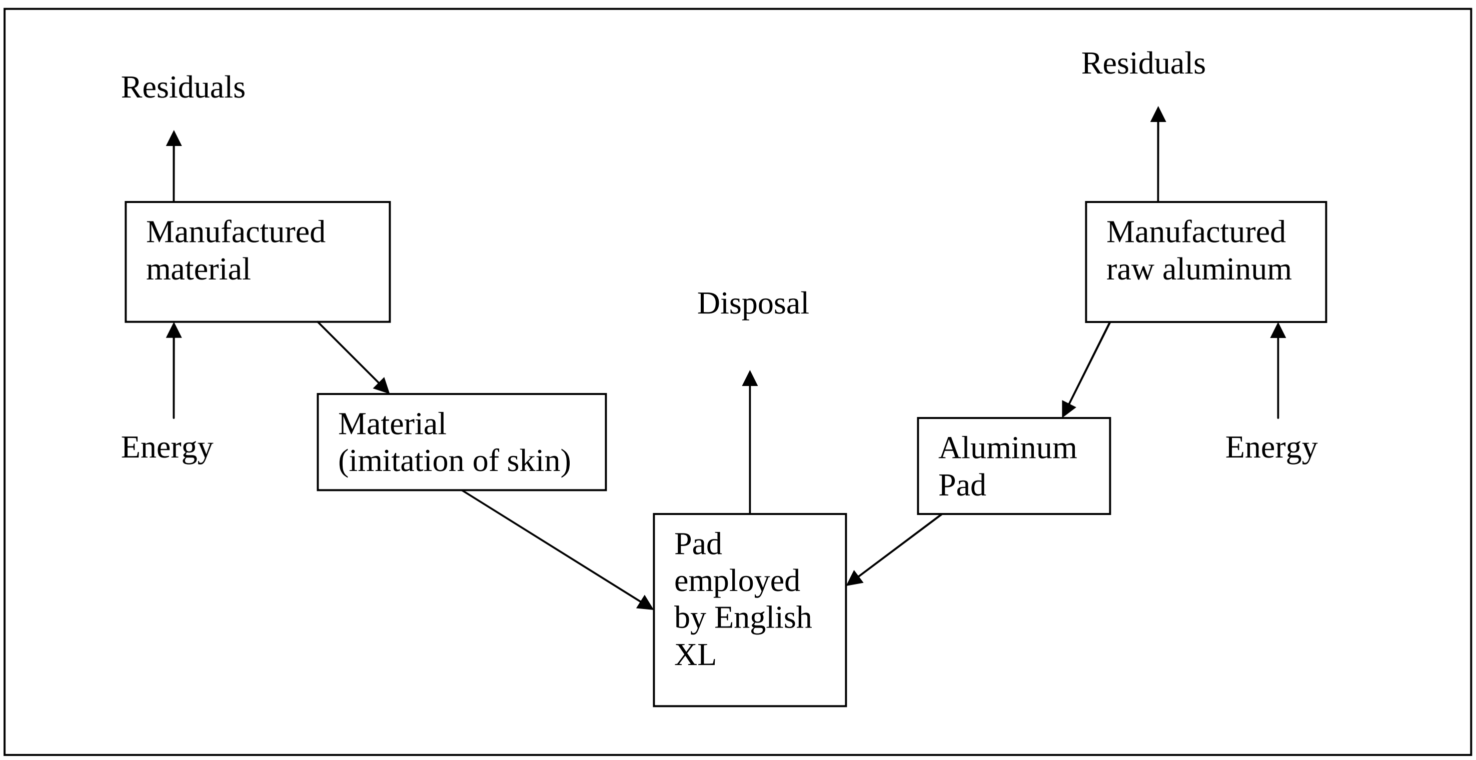

Figure 6.2

The life cycle of the final product, the 1/8 inch diameter aluminum pad with the chosen material which mimics the human skin on wet surfaces

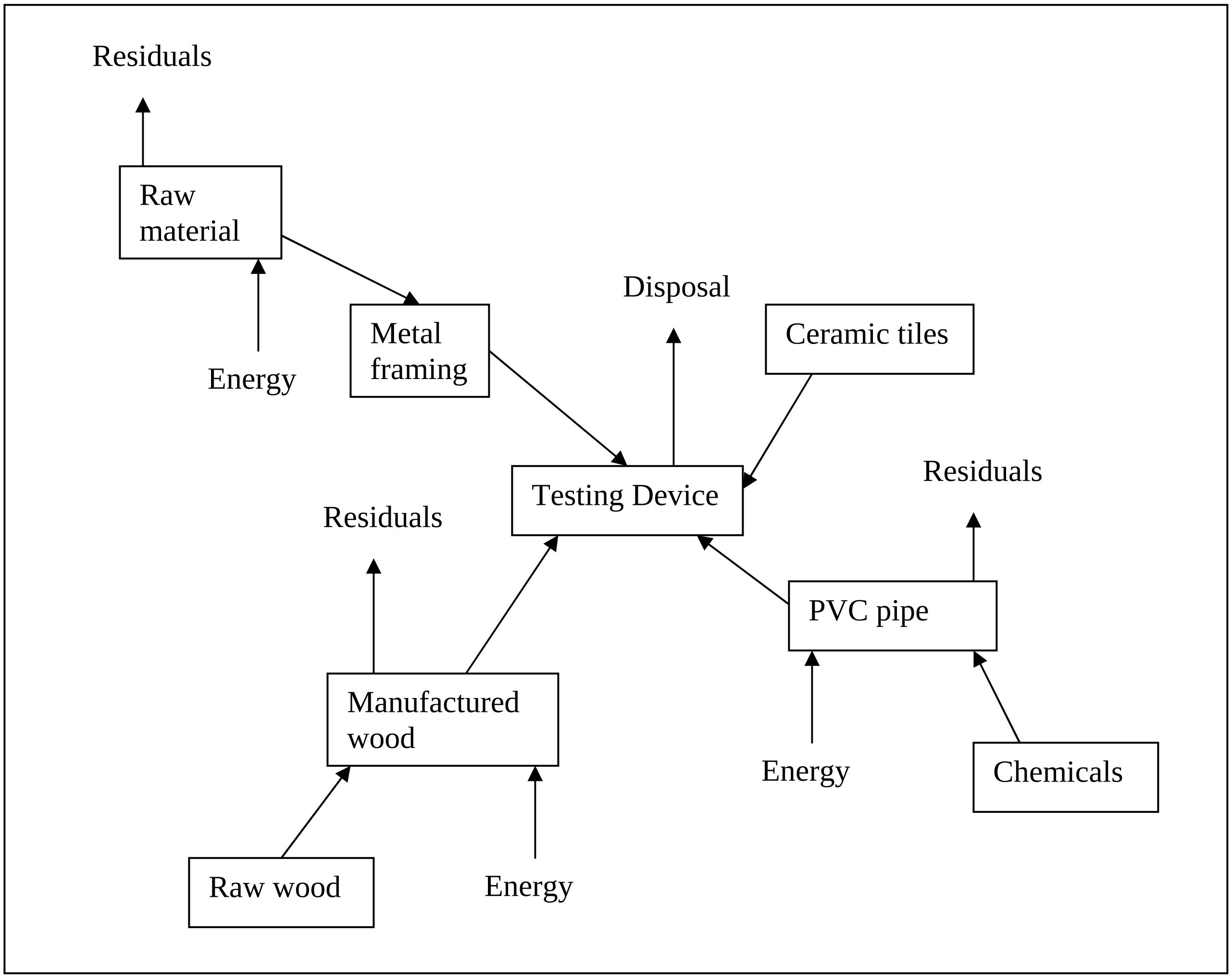

Figure 6.3 The life cycle of the testing device.