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Design of a Folding Floor Trimming Device

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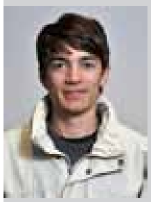

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Abstract

This report documents the complete design process of the Duro-Last Folding Floor Trimmer, a part of the company's response to work-related injuries. This device is expected to improve on the existing trimming system primarily in the areas of safety and ergonomics, while also making improvements in speed and efficiency. A set of measurable objectives was drawn up, revolving around these areas of improvement. A systematic process then generated two new design concepts in conjunction with the existing system. The three systems were rated against one another in a decision matrix and were reviewed by the client, as well as the design team and third-party sources. The concept selected as a result of these techniques was validated through the use of 3D modeling, computational analysis, hand calculations, prototyping, safety analysis, and cost analysis. This report describes the design process to the point just prior to the build phase.

I. Introduction

Duro-Last Roofing, Inc. was founded in 1978, at a time when most commercial roofing systems failed to provide long-term reliability and required continuous maintenance. The company's founder, who at the time was a fabricator of swimming pool liners, proposed the idea that if a pool liner membrane could be used to hold water in a specific location, it should also be able to keep water out of a specific location as well. This idea led to the development of the single-ply thermoplastic roofing membrane that Duro-Last still uses today.

The majority of roofing failures at the time, and still today, were the result of poor workmanship by the contractor as the roof was assembled on-site. To ensure a higher level of quality than the competition, Duro-Last began to fabricate custom roofs in the factory, according to each specific job. Roughly 85-90% of the roof fabrication and seam welding today is done under controlled factory conditions and Duro-Last has become the world's largest manufacturer of prefabricated roofing systems.

1.1 Recognition of Need

Duro-Last Roofing, Inc. has a need to improve on its existing system for trimming edge scrap from prefabricated roof deck sheets before they are packaged. (Note: the term "deck sheet," used by Duro-Last in reference to its prefabricated roofs, is used likewise throughout this report.) This project was conducted in response to several safety and ergonomic-related incidents that occurred on the production floor as a direct result of the current system, which required the worker to bend over from a standing position several times a shift and trim the deck sheet edges by hand, using a straight-edge and utility knife.

Although the workers were required to wear cutting gloves and to stretch periodically when performing this task, the risk of cuts, lacerations, and back injuries remained a concern. Each work-related injury to an employee cost Duro-Last thousands of dollars and tarnished its hard-earned reputation as a safe working environment. Replacing the current process with a device that is specifically designed with safety and ergonomics in mind, which also reduces the time required to perform the task, would accomplish three main things. First, the company will continue to prove itself to be a safe working environment. Second, the company will save a considerable amount of money on work-related injuries. Finally, speed and efficiency will be improved upon in the area of deck sheet trimming, which will ultimately translate into cost savings.

1.2 Problem Definition

The problem is defined by a set of measurable objectives, which define the function, size, cost, safety and performance of the system. Objectives specific to this project include the following required characteristics for the trimming device:

1. Completely eliminates the need for employees to bend over during any part of the cutting process, or provides an ergonomically-friendly alternative to bending
2. Conforms to all current Duro-Last and OSHA safety standards
3. Requires user input force of no more than 40 lbs., both to operate and to transport
4. Makes straight cuts, determined by visual inspection, and deemed satisfactory by company supervisors
5. Cuts through a maximum of two layers of deck sheet, each sheet having a maximum thickness of 60 mils (0.060"); must succeed 100% of the time
6. Performs a minimum 20-foot cut in under 10 seconds, from the time the device is positioned
7. Is durable under repeated use and requires routine maintenance less than once a month. Additionally, the blade must be able to be replaced by any employee using common tools (screwdriver, Allen wrench, pliers, etc.)
8. Can be produced within $4,000 budget per unit.

II. Concept Generation

From the recognition of need and problem definition, three design concepts were generated using two known methods: benchmarking and functional decomposition.

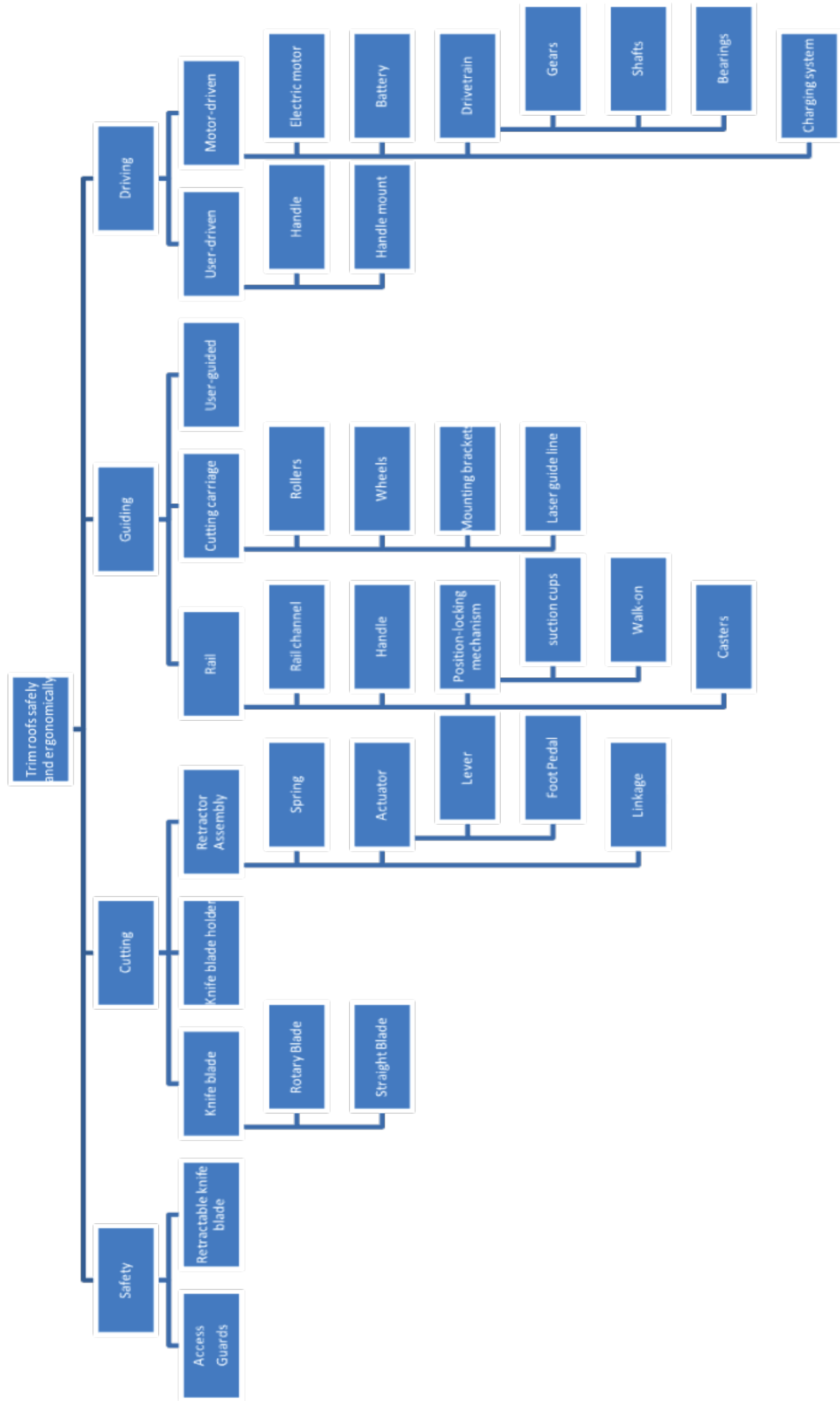
2.1 Benchmarking

Benchmarking is the process of developing design concepts by comparison to other comparable devices and systems currently employed in the industry. The specific industry of concern is that of single-ply thermoplastic roofing. The statistical and technical standards of the industry are set and controlled by a number of companies that make up the organization called SPRI (Single-Ply Roofing Industry). The design team investigated this organization in order to find a list of companies within this industry. Several notable companies have obtained membership within SPRI; these companies include, but are not limited to, Duro-Last Roofing, Carlisle Syntech, Dow Roofing Systems, Firestone Building Products Division, and DuPont Company. Each of these companies was researched by the design team in the hopes of discovering a trimming device or system used by one of Duro-Last's competitors. Through this research, the group discovered that only Duro-Last prefabricates deck sheets in its own factories before they are sold; this helps to ensure higher weld integrity, as on-site welding is generally of poorer quality. Consequently, it is the only company that requires trimming of roof edges in the factory. Thus no direct alternatives to Duro-Last's trimming system currently exist in the industry and a completely original design must be developed.

2.2 Functional Decomposition

Functional Decomposition is a process of design concept generation that breaks a system down into multiple system types and then proceeds to break down each alternative by sub-system and by function until the most basic elements of the overall system have been reached. A functional decomposition developed by the design team for the roof edge trimming system can be found on the following page.

Figure 1: Funtional Decomposition



III. Concepts

From the benchmarking and functional decomposition methods described in the previous section, the design team generated three design concepts. The first concept is the current system used. It is referred to as the datum, which means that the other two design concepts will be judged for their strengths and weaknesses by comparison to the current system. The three concepts are listed below:

RT1: The existing trimming system, which requires a utility knife and straightedge; datum
RT2: An employee-propelled, self-guided rolling device
RT3: A self-propelled, self-guided device

3.1 Concept #1 (RT1)

RT1, the system currently employed by Duro-Last, involves a worker bending over and using a utility knife and a straightedge to trim roof edges. Throughout its history, the company has been able to consistently deliver roofs with clean, straight edges to its customers. Essentially, the current method does provide quality results with respect to the product. However it clearly violates several key measurable objectives defined above.

3.2 Concept #2 (RT2)

RT2 is a user-driven, push-behind cutting system designed to be used on its 20 ft. rail to help ensure straight-edge cuts. This system would improve in the areas of safety and ergonomics, as the user would operate it from a standing position, far away from any sharp blades. It would also be easy to use and very versatile. The system is not without its drawbacks, however. It is more complex than the current system and so there is a greater chance of maintenance being required than with the current, almost-maintenance-free system. It also costs more money to build and maintain than the current system does.

3.3 Concept #3 (RT3)

RT3 is a self-driven cutting system that requires the user only to position the cutting axis. It will need to supply its own power, as it must be transported around the cutting floor, making power cords impractical. Like RT2, it will not have the option of being used independently of the straight edge. The entire assembly will have to be moved into position whenever a cut needs to be made. The cutting process would require no user input and could be set to any desired speed. RT3's features are outlined below.

IV. Concept Evaluation

The three concepts were evaluated using four techniques common in industry: engineering judgment, client feedback, third-party feedback, and a decision matrix.

4.1 Engineering Judgment

The design team evaluated each design concept by developing lists of strengths and weaknesses and comparing these attributes to each other. The strengths and weaknesses of each system are identified below. (Note: The term "measurable objective" has been abbreviated to "MO" to save space.)

RT1 (datum)

<u>Strengths</u>
- Requires very little force input from the user to operate or transport (MO #3)
- Is capable of making consistently-straight cuts of any length or in any direction (MO#4)
- Proven to consistently cut through two layers of membrane at the seams (MO#5)
- Requires only a knife blade change as part of its maintenance (MO #7)
- Very inexpensive (MO #8)

<u>Weaknesses</u>
- Requires the employee to bend over to make the cut (MO #1)
- Requires the employee's hands to be dangerously close to the exposed blade (MO #2)
- Cutting time and quality is heavily dependent on employee skill and is variable (MO #6)

RT2 (walk-behind unit)
Strengths
- Does not require the worker to bend over for any part of the process (MO #1)
- Keeps the worker far away from any exposed blades (MO #2)
- Can easily make straight cuts of any length or in any direction (MO #4)
- Reduces amount of variability in the cutting time from user to user (MO #6)

Weaknesses
- Weighs more than current system and is more difficult to position or move (MO #3)
- Requires more maintenance than current system (MO #7)
- More expensive to build and maintain than current system (MO #8)

RT3 (automated, motorized system)
Strengths
- Requires no bending over to trim material (MO #1)
- Does not require the user to come in contact with any cutting tool (MO #2)
- Requires no input force from the user to cut material (MO #3)
- All cuts are guided by a straight edge for consistent straightness (MO #4)
- Cutting speed could be set to any desirable level and would be consistent each time (MO #6)

Weaknesses
- Most difficult to relocate and position, possibly requiring two workers (MO #4)
- Will likely weigh more than the other systems because of the motor and battery (MO #3)
- Most complex system and would require more maintenance than the other concepts (MO #7)
- Most expensive of all systems to build and maintain (MO #8)

The design team determined that the design concepts RT2 and RT3 are superior to the current system, based on the strengths and weaknesses and suggested that RT2 would ultimately be the best concept to select for the project. The design team felt it was necessary to concentrate primarily on the elimination of the worker's need to bend over and to improve on the system's safety.

It may not be preferable to conceive a fully-automated self-propelled device to achieve these requirements for several reasons. First, in comparison to RT2, a motorized device would be far more complex from a design standpoint. Because of its complex nature, such a concept would take a long time to design and could provide the most unexpected results when testing. Secondly, RT3 may require too much maintenance. Thirdly, failure is most likely to happen, especially considering the fact that this concept can be easily misused by a careless production worker. Finally, this concept would be far more expensive than RT2 and would push the team closer to the budget limit. Since this device will be an original design, the design team would prefer to leave a greater financial buffer during the development stage of the prototype to account for any redesign or rework that may be required.

To conclude, the design team felt that RT2 would be the most appropriate concept, as it is simpler to design. It will require less maintenance and can be built more quickly, allowing more time for possible modification.

4.2 Client Feedback

The design concepts were proposed to the client representatives, Mitch Gilbert, Mark Draves, and Chad Davis, for feedback. All agree that a straightedge is absolutely necessary to perform a straight cut. They preferred the RT3 concept, despite the possibility that it would require more maintenance. A combination of the two methods (current device RT1 and RT3) was also considered. By doing this, RT3 would be used to perform long cuts (90% of the cuts) and the utility knife would still be used to perform smaller cuts with the help of a shorter, more manageable straight edge.

4.3 Third-Party Feedback

Third-party feedback was also received from Ron Albertson, one of the workers on the folding floor. He also was convinced that the device would not steer unless guided by a straightedge, making it difficult to produce straight cuts. However, he was more confident in the push-behind concept for the following reasons: 1.) It is not as complex as the self-propelled concept 2.) It does not involve the complexity of a motor and would require much less maintenance.

4.4 Decision Matrix

A decision matrix was generated to assist with the design concept selection. The team elected to use a 9-3-1 weighting system to differentiate between the more important criteria versus the less important criteria. Criteria receiving a weighting of 9 were considered to be "very important" in the design selection; criteria receiving a weighting of 3 were considered to be "somewhat important" in the design selection; criteria receiving a weighting of 1 were considered to be "not very important" in the design selection. After the criteria were weighted, each design concept was rated based on its level of adherence to the given criterion. The following scale was used in the rating process:

+3: The criterion is met in a manner that is far superior to the datum
+2: The criterion is met in a manner that is somewhat superior to the datum
+1: The criterion is met in a manner that is slightly superior to the datum
0: The criterion is met in a manner that is equal to the datum
-1: The criterion is met in a manner that is slightly inferior to the datum
-2: The criterion is met in a manner that is somewhat inferior to the datum
-3: The criterion is met in a manner that is far inferior to the datum

As previously stated, RT1 is the system that Duro-Last currently uses. Therefore, it was the datum and received all zero ratings. RT2 and RT3 were scored against the datum by multiplying the rating by the weighting for each criterion and then adding up the products. If the final score was positive, it indicates that the concept, overall, is superior to the datum. If the final score was negative, it indicates that the concept is inferior to the datum.

The decision matrix for the three concepts can be found below. The first column in the matrix contains the criteria for the project. The second column contains the weights for each criterion, as described above. The next three columns show the ratings for each of the three concepts, based on the given criteria. The bottom row shows the final scores for each design concept, determined using the process described previously.

Figure 2: Decision Matrix

Criteria	Weighting	Concept		
		RT1 (datum)	RT2	RT3
Safety	9	0	3	2
Ergonomics	9	0	3	3
User-Friendliness	3	0	2	3
Transportability	3	0	1	-1
Reliability	3	0	1	0
Serviceability	3	0	-1	-2
Cost	1	0	-2	-3
Weight	1	0	-2	-2
	Total	**0**	**59**	**40**

Both RT2 and RT3 were shown to be far superior to the datum according to the decision matrix. Therefore, the design team felt confident that RT1 could be discarded as the primary method for roof trimming. RT2 was the superior design of the three that were compared, having received a score of +59, compared to RT3's score of +40.

V. Concept Selection

These findings of the concept evaluation methods were presented to the client. Based on engineering feedback, prior client and 3rd-party feedback, and the decision matrix, the client unanimously agreed that RT2 would be the ideal choice for trimming deck sheet edges. RT2 will now be referred to as the Folding Floor Trimmer.

VI. Product Development

Having selected a design concept, the project moved into the product development stage, which consists of six primary methods: 3D modeling, application of classical engineering calculation and theory, computational analysis, prototyping, safety analysis, and cost analysis.

6.1 3D Modeling

3D modeling of the assembly is done to ensure that the design can be manufactured and assembled as intended before a single part is produced. Duro-Last requested that the design team generate all 3D models and 2D detail drawings in Autodesk Inventor Professional 11, the software package used by the company. Some examples of the 3D modeling results can be seen in the figures below.

Figure 3: Cutter Carriage Exploded View

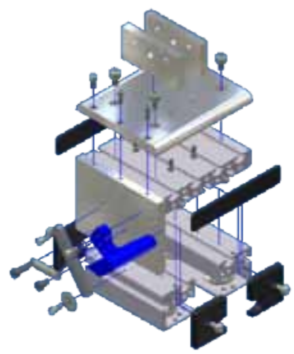
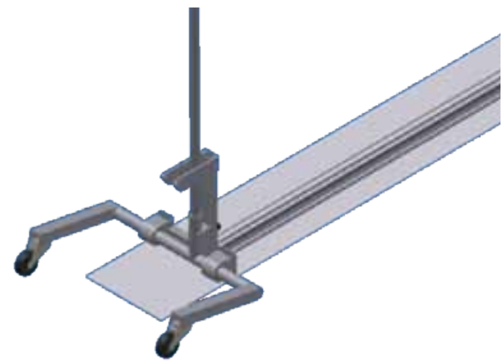


Figure 4: Lift Assembly



6.2 Classical Engineering Calculation and Theory

This section involves the use of basic engineering theory and equations learned throughout the degree program to provide evidence that the design concept will work as intended. A static loading analysis was conducted on the main rail structural member to determine how much the beam would deflect under the weight of the device when the assembly is lifted for transport. Since the lift assemblies are used for lifting and positioning the device and their weights are not exerted upon the beam, these weights were not considered in this analysis. The total weight of all of the involved parts, including the weight of the beam itself, was found to be 50.87 kg, which was converted to 498.5 N of force.

This force was taken as a concentrated force acting at the midpoint of the beam, as this would yield the worst-case scenario for static stress and deflection. Using the appropriate equation for a simple beam, supported at both ends with a centrally-located point force, the total deflection was calculated to be 31.67 mm, located at the beam's midpoint. Knowing this deflection helped the design team to determine how high the lift assembly must lift the rail in order to prevent the device from dragging on the ground during transport. The static stress was determined to be 29.56 MPa. The yield stress for 6061-T6 aluminum, according to Gere's Mechanics of Materials – 6th Edition is 270 MPa. This produces a safety factor of >9:1, which was deemed acceptable by the design team.

To back up these calculations, the design team verified its work with the company that produces the extruded aluminum used in the rail assembly. Item® has a comprehensive website that includes automatic calculators that assist with the determination of beam deflection and primary stresses. The operating parameters for the rail were entered into the calculator; the results can be found in Appendix I. The online calculator returned a maximum deflection of 31.67 mm and a static stress of 29.57 MPa, virtually identical to the results obtained by the team's analysis. Upon deeper investigation, the team learned that the calculator is based on the very same equations that the team has employed. Thus, the team felt confident with the calculations.

Calculations were also completed on the knife arm in order to establish a starting point for experimentation with spring stiffness on the final prototype in ME 481, as well as to provide a template for resultant calculations during testing. A free body diagram was drawn for the knife arm in both its up and down positions, as can be seen in Appendix 1. Through calculation, the group established a starting spring stiffness of 13.5 lb. Resultant shear stresses acting on the mounting bolts were equal to 16.8 and 8.4 lb in the up and down positions respectively. These stresses are far below the yield strengths of the bolts.

Free body diagrams and mechanics equations were also performed on the pedal in its up and down positions in order to get an estimate of an input force required to move the pedal up or down. The required force to move the pedal was calculated to be 0.845 lb. Calculations were also done to ensure that the weight of the pedal wouldn't counteract the downward force of the blade on the material enough to prevent proper cutting at the determined spring force. The tension force in the linkage required to hold the pedal up was determined to be 1.56 lb, which is not enough to affect the downward pressure of the blade on the material.

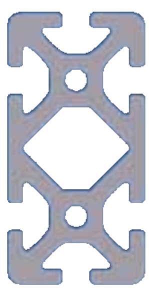
Static deflection equations were applied to the lift arm assemblies to ensure that they would not deflect excessively under the weight of the device when lifted. The appropriate equations were taken from a solid mechanics textbook for the given loading conditions. The total deflection in the lift arms was found to be 0.045" at the location of the casters, which was deemed acceptable by the design team.

Finally, bearing life equations were applied to the double bearing units used in the cutting carriage. These equations were supplied by Item ® and were verified in Juvinall's Fundamentals of Machine Component Design – 4th Edition. The bearings were found to have extremely high service lives in the given application. The design team acknowledges that these bearings are probably far more robust than required for the application. However, the team chose to incorporate them anyway because of their compact size and proven performance in several of Duro-Last's other machine design applications. These bearing units can be found on several of the company's machines and, although some of them have been in service for 10 years or more, none of them have ever needed replacement. The design team feels that using these bearings will provide security that the machine will require less maintenance during its time in service.

6.3 Computational Analysis

Computational Analysis is the use of a computer to aid in the calculation of stresses and deflections (such as Finite Element Analysis or FEA), as well as the investigation of part and sub-assembly interactions while in motion. The design team attempted to back up the theoretical calculations with FEA data. However, the program gave results that did not agree with the hand calculations, particularly with the rail beam. Since the results of the website calculator agreed perfectly with the results of hand calculations and the group is confident that Item® calculators give accurate results for its products, the team felt it was acceptable to reject the FEA data. The team proposes that the profile of the extruded beam is too complex for the FEA package to handle (see Figure 5).

Figure 5: 40x80 Extruded Aluminum Profile



6.4 Prototyping

To help the team better understand the form, fit and function of the Item® pre-fabricated machine building system to be used in the device, a small, partial prototype was constructed using standard parts from Duro-Last's inventory. By constructing this prototype, the team developed a better understanding of the machining and construction process that will be required to build the final prototype.

6.5 Safety Analysis

The most important factor in determining the feasibility of a device or system is safety. An unsafe device will likely cause injury to employees, which costs the company money and its reputation as a safe working environment. It also brings into question the company's moral and ethical stand toward its employees and raises the risk of lawsuits. Therefore, a safety analysis was carried out on the folding floor trimmer concept to ensure that the new device would be safe to integrate, operate, and maintain. The analysis also needed to ensure that areas most likely to cause an accident or failure have safeguards in place to minimize or eliminate the possibility of injury. An analysis of the liability relationship between the company, the employees, the design team, and the representing university will be discussed in this report. Additionally, a hazard index for the folding floor trimmer was generated to assess the possible injury risks present.

6.5.1 Liability

The design team shall be responsible for the following:

- The folding floor trimming device shall comply with all existing OSHA and Duro-Last safety codes
- The folding floor trimmer device shall be rigorously tested by the design team until the operation and safety of the entire system can be verified
- The design team shall generate a Standard Operation Procedure (SOP) for the folding floor trimmer that shall provide for the safe and efficient operation and maintenance of the device
- The design team shall collaborate with supervisors and work with them directly to improve the system. This shall continue until an agreement can be reached that the device is acceptable before it is placed into service
- Per signed contract, Saginaw Valley State University assumes zero liability for any injuries or damages incurred by the client company as a result of the project
- The design team shall assume zero liability for injuries or damages incurred by the client company as a result of use that deviates from the procedures listed in the Standard Operation Procedure.

6.5.2 Hazard Index

The design team has developed a hazard index in order to investigate the possibility and severity of accidents and injuries that could result from use of the device. This index can be found in Figure 6. The first column provides a description of the hazard present. The second column indicates the level of frequency with which the hazard is likely to occur. The third column indicates the severity of the consequences resulting from the given hazard occurrence. The fourth column indicates the hazard assessment score for the given hazard occurrence. The final column indicates whether or not corrective action is required to prevent the hazard from occurring.

Figure 6: Hazard Index

Hazard Description	Level	Consequence	Risk	Criterion
Knife blade breakage	B	IV	16	Acceptable with review
Knife carriage falls off track	D	III	14	Acceptable with review
Knife cuts worker	E	II	15	Acceptable with review
Worker trips over track	C	III	11	Acceptable with review

As can be seen in Figure 6, all risks assessed were assigned a criterion of "Acceptable with review." This means that since the operation and maintenance of the device will be supervised, the hazard risk is acceptably low. Some additional precautions could also be taken. The knife blade can and should be properly enclosed so that if the blade should shatter for any reason, sharp pieces are very unlikely to injure a worker. The product should be fully inspected every time it is maintained to monitor wear and replace components before they fail. Rigorous testing of the device should be completed before it is placed into service, to address any issues that may arise. The rail could be covered in OSHA hazard tape to make it more visible and to prevent accidental tripping by workers. The Standard Operation Procedures can and should warn employees to keep all body parts as far from the trimming device as possible while it is being raised or lowered. Employees could also be required to wear cutting gloves while handling the knife blades, to prevent cuts and lacerations.

6.6 Cost Analysis

The cost of the new system to the company can be determined by first adding up the cost of all components and labor used to construct one of the devices and then multiplying it by the total number of devices required. Duro-Last has twelve folding floors company-wide and, therefore, requires twelve units. The total cost to construct one folding floor trimmer will be approximately $2750.59, for a total cost of $33,007.08 for all twelve devices.

Duro-Last follows a five-year Return on Investment policy (ROI), which means that new devices and projects must save the company enough money to pay for themselves in less than five years. The Engineering Services/Machine Build department determines cost savings based on three main criteria: scrap, safety, and time. The amount of edge scrap removed from the deck sheets is not expected to change when the new system is integrated. Therefore, no foreseeable cost savings can be determined in this area.

The safety costs can be broken down into two main categories: direct and indirect. Direct costs refer to the medical and compensation expenses incurred by the company as a direct result of the specific injury. Indirect costs refer to the additional expenses incurred by the company over time as injuries occur, primarily costs resulting from increases to workman's compensation insurance premiums. The design team investigated the company's history of injuries directly related to the folding floor trimming system over the past five years. These injuries directly cost the company a total of $1705.70. The Duro-Last safety department informed the design team that the average indirect costs from injuries are equal to approximately seven times the direct costs, setting them equal to approximately $11,939.90; thus, total costs equal approximately $13,645.60. Assuming the employee uses the folding floor trimmer in strict accordance with the Standard Operation Procedures, the possibility of knife blade and ergonomic injuries, which are the two primary causes of injury on the current system, will be virtually eliminated. Thus it will be assumed that 100% of these costs will be recovered by the client.

To investigate the time saved with the new system, the design team began by spending time on one of the folding floors in the Saginaw, MI, plant, observing workers as they trimmed roofs. The design team estimates that the same amount of time will be required to position the old and new trimming devices and to remove scrap. Therefore, the only time period of concern to the team was the actual trimming time, since this is the particular part of the current process that contributes the ergonomic and safety issues. The trimming process was timed, starting from the point at which the worker bent over and began trimming the roof and ending when the cutting process was finished. An average of ten seconds was found to be required to trim 20 feet of the deck sheet using the utility knife method. Given that the new system will simply involve pushing a cutting carriage across the rail's 20-foot length at an estimated walking speed of 3 mph, the cutting time is reduced to approximately 5 seconds.

The team learned that production workers earn an average hourly wage of $12.50. At this rate, it costs Duro-Last about $0.03 per cut in employee wages using the old system. The new system would reduce that amount to $0.02 per cut. The team also estimated that a new deck sheet is pulled out onto a folding floor every ten minutes, meaning that about 144 deck sheets are trimmed over a 24-hour period per folding floor. Most deck sheets are also wider than 20 feet, meaning that they must be laid out partially, trimmed, then pulled out further and trimmed again, at one or sometimes both ends for standard trimmings. To be conservative, the team estimated that about three cuts are performed per deck sheet, although four or more trims are occasionally performed per deck sheet. This translates to approximately 432 cuts per day per folding floor, which, with the new system, would result in a savings of $7.50 per folding floor, per 24-hour day in employee wages. Again, each plant contains three folding floors and there are four plants company-wide. Therefore, the company would save approximately $90.00 a day in trimming wage costs. Over a five-year period, at this rate, the savings would amount to $164,250.00 with the new system. This total, added to the injury savings, returns a gross, five-year savings of $177,895.60 to the client, or a full return on investment within ten months of deployment.

VII. Results/Discussion

As stated previously, the success/failure of the results of the project shall be rated by their level of adherence to the measurable objectives laid out in the early stages. In this section, each measurable objective will be discussed in relation to the final results obtained.

1. *Completely eliminates the need for employees to bend over during any part of the cutting process, or provides an ergonomically-friendly alternative to bending*
   The folding floor trimmer allows the worker to trim deck sheet edges completely from a walking position, eliminating the bending over that is required with the current system. Tall handles on each end of the trimmer eliminate the need to bend over and pick up the device for transport or positioning. Instructions for ergonomically-correct squatting techniques to prevent bending over to remove

scrap will be discussed in the Standard Operation Procedures.

2. *Conforms to all current Duro-Last and OSHA safety standards*
All proper provisions will be made to properly guard the knife blade from the operator. The operator will not be required to come in contact with any exposed blade to complete a cut.

3. *Requires user input force of no more than 40 lbs., both to operate and to transport*
This measurable objective could not be fully determined at this time. While the design team feels confident that the concept will not require excessive force to operate or to transport based on the configuration and weight, the team has no concrete way of accurately measuring or calculating the required force without actually building the prototype first or constructing a test fixture, which did not seem like a cost-effective alternative to the design team, given the scope of the project. The final prototype will be measured for the input forces required and every effort will be made to meet this 40 lb. maximum input force requirement.

4. *Makes straight cuts, determined by visual inspection, and deemed satisfactory by company supervisors*
The device will be operated 100% of the time on the rail, which ensures consistent straight cuts.

5. *Cuts through a maximum of two layers of deck sheet, each sheet having a maximum thickness of 60 mils (0.060"); must succeed 100% of the time*
The design team has no time or budget-conscious method available to quantify the downward force required to penetrate the deck sheets at the seams. Therefore, the team will be experimenting on the final prototype in ME 481: Senior Design II with various blade types and sizes, as well as different tension spring sizes to ensure that there is enough blade clearance and downward force to cleanly penetrate deck sheets at the seams. However, it was determined through the use of solid modeling that the prototype has enough blade clearance built in to allow it to fully penetrate a weld seam using 0.060"-thick sheets.

6. *Performs a minimum 20-foot cut in under 10 seconds, from the time the device is positioned*
Assuming an average walking pace of 3 mph, the device should be able to complete a 20-foot cut in about five seconds.

7. *Is durable under repeated use and requires routine maintenance less than once a month. Additionally, the blade must be able to be replaced by any employee using common tools (screwdriver, Allen wrench, pliers, etc)*
The design team used classical mechanics and machine design equations to validate the design (see section 7.3). The design team suggests that only the knife blade will likely require regular maintenance. Therefore the device has been designed to allow easy removal and installation of the blade.

8. *Can be produced within $4000 budget per unit.*
The final cost for one unit is $2750.59.

VII. Design Impact

The design impact determines how the project will or will not affect certain areas of society. The areas commonly considered are social impact, political impact, ethical impact, environmental impact, and economic impact. Since the device will be used internally at Duro-Last 100% of the time and no devices shall be built for the purpose of selling them to outside consumers, it can be assumed that the device shall not create any political impact. Additionally, since the folding floor trimmer, like its predecessor, does not require any power input other than human effort and contributes the same amount of waste (e.g., scrap material and used knife blades), which can be properly recycled or disposed of, it can be assumed that the device offers no additional environmental impact. However, the device impacts the remaining areas in the following ways.

8.1 Social Impact

The folding floor trimmer is being implemented in order to remove a current system that has been deemed unsafe. If the new system is able to deliver the same quality result as the current system, but without the health hazards, it will contribute positively to Duro-Last's perceived commitment to employee safety. Additionally, the aesthetics of the new system are far more professional than the current system. Since Duro-Last regularly brings contractors on tours through its Saginaw plant, the new device will help to project a more professional image to potential customers.

8.2 Ethical Impact

The folding floor trimmer will be proven to be a safe alternative to the currently hazardous system. The simple fact that Duro-Last has identified this health risk and chosen to invest in the development of a safer alternative indicates its ethics. If Duro-Last had recognized this hazard and chosen to do nothing, company ethics could be questioned.

8.3 Economic Impact

The cost analysis section of this report shows that the new system significantly cuts down on company costs relative to the current system. Injury costs are virtually eliminated and overhead costs are reduced due to the decreased time required to trim deck sheets.

IX. Conclusions/Recommendations

Duro-Last Roofing, Inc. had a need to replace a deck sheet trimming system currently in use that had been deemed to be unsafe and ergonomically-incorrect. The current system was analyzed in order to identify specific problems, which helped to generate a list of measurable objectives for the project. From these measurable objectives, concepts were generated and evaluated. A single concept was chosen and was then evaluated using proven engineering methods. The new system will reduce the number of work injuries caused by the trimming of deck sheets, while increasing productivity.

Through its experiences, the design team has developed a list of recommendations for future design projects. Design teams should observe current practices as much as possible, in order to get a better understanding of areas in which time or money can be saved. This also helps the team design a new system that can be seamlessly integrated. The design team suggests that future teams work to build parts and prototypes as quickly as possible, leaving more time for modification and improvement. Finally, good documentation is critical to the success of a project. It is important to have physical evidence of meeting agendas, calculations, Research and Development, and concept generation stages to help the design team keep track of progress.

X. References

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