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Final Design Report

MECH 4860 - ENGINEERING DESIGN

Design and Implementation of a Machine Guarding System for a KOMO CNC Router

Group 5 – TAZE Consultants

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TAZE Consultants

December 1st, 2014

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Dear Dr. Labossiere:

On behalf of team 5, it is my pleasure to present to you TAZE Consultants Final Design Report. The report outlines how we engineered a new design for the guarding system of the KOMO CNC machine at DECOR Cabinet Company. The report includes a brief yet detailed project description, the steps taken to arrive at our final design as well as all the details to the chosen design.

Should you have any questions, comments or concerns, please contact myself at
or

Yours sincerely,

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Travis Defoort

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Executive Summary

The team worked in collaboration with a locally owned, semi-custom cabinet company: Decor, to design an implementable guarding system for a KOMO CNC router machine.

The final design consists of physical barriers placed around the machine's envelope, with the exception of the area in front of the material loader and around the CNC router table. These barriers are 72 inches tall with a 6 inch ground clearance. Two access doors are provided, one by the vacuum pump (50 in wide) and one by the tool changer (48 in wide). The access doors each require a safety interlock switch which can be purchased for $90.00. The total cost to purchase the metal required for the physical barriers is $5,575.00. Safety floor mats were placed in an L-shaped configuration between the material handler and the router table (17.85x132 in), as well as in front of the router table (36x108 in). This design requires four mats, 17 ft of ramp trim, 22.5 ft of machine trim and a manual reset controller. The total cost to purchase the required parts to assemble the safety floor mat system is $4,841.70. A photoelectric sensor is placed in the entrance of the material loader. This sensor is 72 in tall and has a cost of $1,737.00. After including projected manufacturing and installation costs to the cost of the components, as well as a 10 % buffer, the total cost of implementing the proposed guarding system was found to be $14,436.63. This price is under the allowed budget and the guarding system eliminates the risk of injury from occurring while using the KOMO CNC router machine. Therefore TAZE Consultants recommends that Decor implement this system.

1. Project Description

Decor Cabinet Company requires an overall machine guarding system that will reduce the risk of injury to its operators and shop visitors while its KOMO CNC router machine is in operation. Decor uses this machine on a daily basis to manufacture cabinet doors for its semi-custom fabrication line. This machine covers a 480 square foot area on Decor's shop floor and contains moving parts that the operator interacts with frequently. Figure 1 shows Decor's current guarding system. This current guarding system does not fully protect Decor's operators and bystanders, and does not meet CSA standards. The new guarding system must stop particles which may become airborne from striking an operator or bystander, as well as prevent access to dangerous moving parts of the automated machinery.

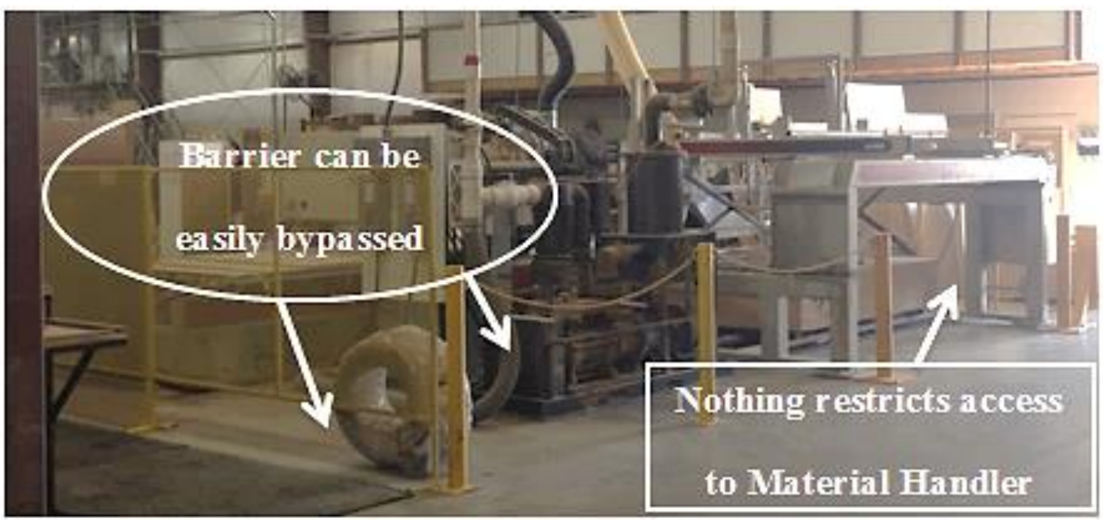

Figure 1: Decor's current guarding system

There are various areas of the machinery that pose a risk to the operator and bystanders. One key area to improve safety is the walkway between the material handler and the CNC Router table, shown in Figure 2. Both the material handler and the CNC Router table are automated pieces of equipment that operate at high speed and will not be stopped by human interaction. The material handler places large sheets of wood on the router table, which produces individual cabinet doors from the sheets. In order for the CNC router to cut through the thickness of the sheet, the operator must enter this walkway and flip the sheet over. This creates a very high risk of injury occurring because the machine could start again while someone is in this area.

Figure 2: KOMO CNC router machine

This project will provide Decor with a plausible solution that can be implemented to reduce the risk of injury to its operators and shop visitors while its KOMO CNC router machine is in operation. This was accomplished by reviewing and meeting CSA standard ZF3204: the safeguarding of machinery. To meet this standard, the client and the team identified areas where injury can occur around the KOMO CNC machine. The main goal of the project is to implement a solution that will make these areas safer for both the operator and any bystanders in the proximity of the operating machine.

1.1. Customer Needs

After meeting with the client, TAZE Consultants identified a list of needs. Each need is established to serve a particular purpose. A customer needs weighting matrix (Appendix A) was completed to objectively prioritize the needs by comparing each individual need with respect to the others. This process allowed the team to set goals for the project. These goals are specific, measurable, achievable, relevant and timely. TABLE I is an ordered list of the customer needs, which was found using the customer needs weighting matrix.

TABLE I: WEIGHTED CUSTOMER NEEDS

	Customer Needs	Evaluation (%)
1.	Meets CSA Standards	22.22
2.	Improves operator and bystander safety	19.44
3.	Quality of the product is upheld	16.67
4.	Machine operates efficiently with guarding in place	13.89
5.	Easy to implement	8.33
6.	Guarding protects while machine is in current position	5.56
7.	Lasts a long time	5.56
8.	Stays within budget	5.56
9.	In-house manufacturability	2.78

In conclusion, the team found that the most important criterion and goal is meeting the CSA standards for safety. The need with the second highest priority is improvement of operator and bystander safety. In-house manufacturability was found to be of the lowest priority, which agrees with the priority ranking given by the client.

1.2. Metrics and Target Specifications

After the needs were identified and prioritized, the team determined metrics and target specifications in order to quantify how the customer's needs would be met. The target specifications are a specific and measurable goal to meet in order to fulfill the customer needs. These specifications were derived from the metrics as assigned to each need. In order to rank the metrics based on their strength of connection to the customer needs, a House of Quality (HOQ) was created (Appendix A). The main body of the HOQ shows the relationship between each metric and customer need. Using the weighted customer needs and the corresponding value given to each metric, the importance of each metric was evaluated. This process is often known as Quality Function of Development (QFD). TABLE II shows an ordered list of the metrics and their target specifications.

TABLE II: QFD HOUSE OF QUALITY METRICS

Metrics		Target Specifications	Evaluation*
1.	Implement physical barriers	> 45% of machine envelope	7.500
2.	Implement electronic sensors	≤ 1 sensor	6.667
3.	Implement automated material handler	No operator required	4.333
4.	Clearly identify danger zone	All danger zones are identified	3.750
5.	Clearly identify sensors	All sensors identified	2.972
6.	Implement barriers with accessibility	≥ 1 access point	2.667
7.	Manual reset of sensors	All sensors with manual resets	1.667
8.	Reduce the number of design components	< 4 guarding systems	1.528
9.	Utilize company welder	Barrier assembly done in-house	1.167
10.	Use off the shelf products	100% standard parts	0.806
11.	Utilize company electrician	100% of wiring done in-house	0.750
12.	Utilize local suppliers	100% of material found in Morden	0.528
13.	Use durable materials	All barriers made of steel	0.500

** Values represent the relationship between customer needs and metrics; (0) no relation; (1) weak;(3) moderate; (9) strong.*

To summarize, the QFD showed the team the most important metrics to focus on are to implement physical barriers and electronic sensors.

1.3. Constraints and Limitations

For this project, five main constraints and limitations were identified to ensure the project met the client's needs. These are outlined in TABLE III.

TABLE III: CONSTRAINTS AND LIMITATIONS

	Constraint	Limitation
1.	Cost	≤ $15,000
2.	Space	< 1ft from machine envelope (480 sq ft)
3.	Manufacturing	Decor prefers to build everything in-house
4.	Accessibility	Operators require frequent access to machine
5.	Health and Safety Standard	Meet CSA standard Z432-04

After this process was completed, the team developed a well-defined project management plan (Appendix B) to ensure that the project would be completed in a timely manner.

With the customer needs, metrics and target specifications, as well as the constraints and limitations all identified, the team was able to confidently move onto the concept phase with a solid understanding of the project.

2. Conceptual Design

Once the requirements for the project were understood, the team began to research various ways to stop an automated machine before human interaction can occur. Four different methods were ultimately selected: proximity sensors, photoelectric sensors, floor mat sensors and physical barriers.

The team took all the solutions produced in the brainstorming session and began to conceptualize different designs. There were a total of eight designs generated using the four different methods to stop an automated machine. In order to achieve the best solution, a concept screening matrix was developed. This matrix scored all the designs produced based on how well they met the customer needs. Through the screening process, the team found that certain methods for stopping the automated machine worked best in specific locations. Using this new found knowledge, the team developed two designs, the preliminary floor mat design (Design A) and the preliminary photoelectric design (Design B). Design A, shown in Figure 3, uses elements of the existing barriers with new physical barriers and two different electronic sensors: safety floor mats and photoelectric sensors. Safety floor mats are used in between the material loader and CNC router machine, as well as in front of the router table. A photoelectric sensor is placed in front of the material loader, while the remaining of the guarding is done with physical barriers.

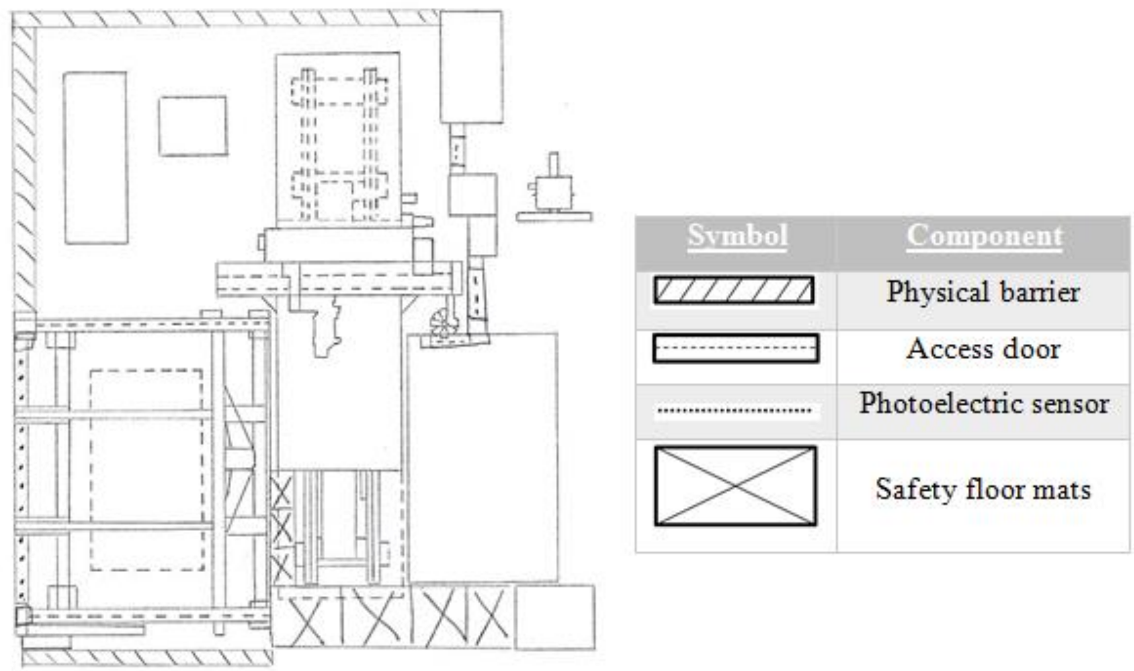

Figure 3: Preliminary floor mat design (Design A)

Design A was the most favourable solution because it had the greatest total score in the screening and scoring processes performed in the conceptual phase of the project. Design A had a total score of 4.639 out of 5. This score was in comparison to all the designs that were generated in that phase.

The main way Design B differed from Design A, was it utilized photoelectric sensors in place of safety floor mats in front of the CNC router table. This was done to reduce the cost of Design A, as initial cost estimates suggested safety floor mats are more expensive than photoelectric sensors. Design B is shown in Figure 4.

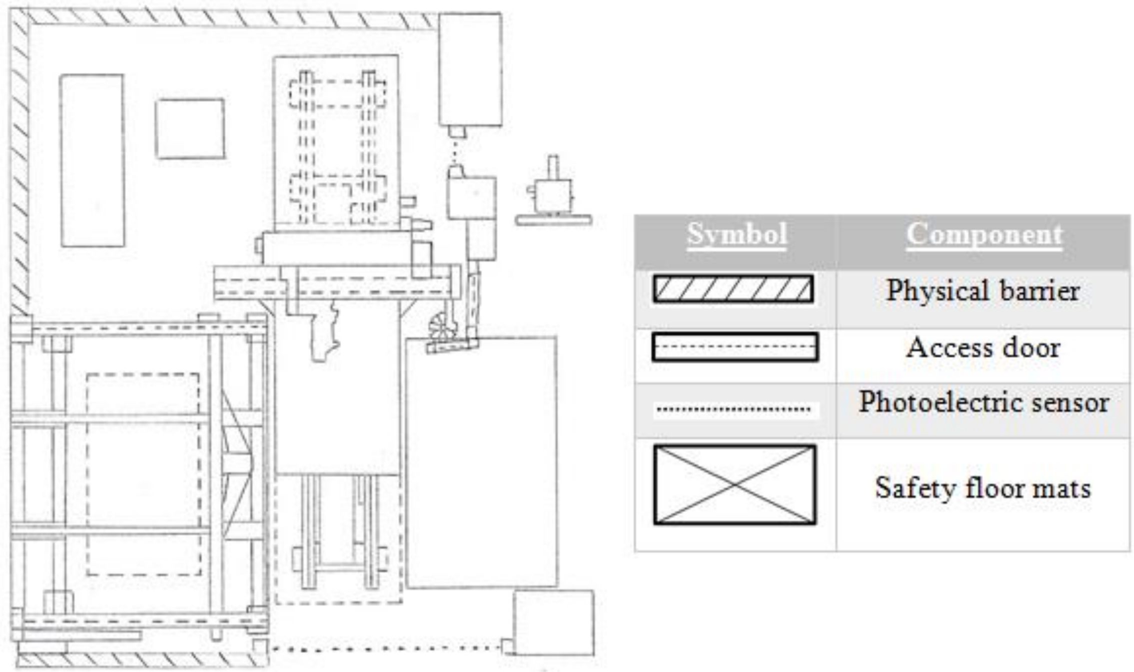

Figure 4: Preliminary photoelectric design (Design B)

Substituting the photoelectric sensor in lieu of the safety floor mats resulted in a lower score during the screening process compared to Design A, with respect to improving operator and bystander safety. The reason being that if an individual is present in the area prior to the machine being in operation, the photoelectric sensor will not detect the person.

The team presented the two recommended solutions in a design review meeting held at Decor's head office. The team met with four members of Decor's management team that is directly affected by, and involved in, this project. All members involved agreed that Design A was the better solution in comparison to Design B. Therefore, the remainder of the meeting focused on altering Design A to the client's preference.

The client suggested that floor mat sensors be placed in the operator's working area, and photoelectric sensors be placed outside of the material loader where the forklift deposits the raw material. The rest of the safeguarding is done using physical barriers. The physical barrier begins at the material loader and goes all the way to the tool changer. The client requested two interlocking gates to be placed in this closed off area. The first door is to be placed close to the pump and bearings of the material loader for service if required. The second door is to be place by the tool changer. Figure 5 shows the design with the suggestions made by the client.

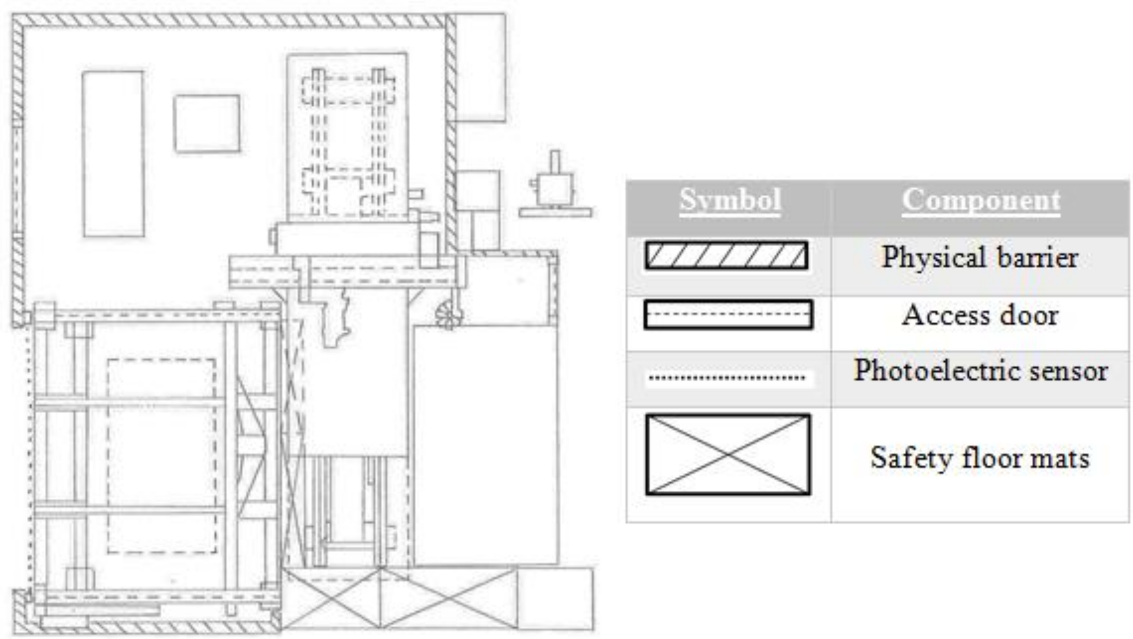

Figure 5: Preliminary access door design (Design C)

3. Final Design

Design C was further developed and optimized in order to produce a final design that incorporates the client's requests while meeting the CSA standards.

3.1. Details of the Design

The final optimized design incorporates three types of guarding systems. A physical barrier encapsulating the less frequently accessed areas, floor mats sensors placed in high access areas to ensure the safety of the operator, and a photoelectric light curtain sensor at the entrance of the material loader to ensure no entry to the area. An isometric view of the design surrounding the CNC KOMO machine is shown in Figure 6.

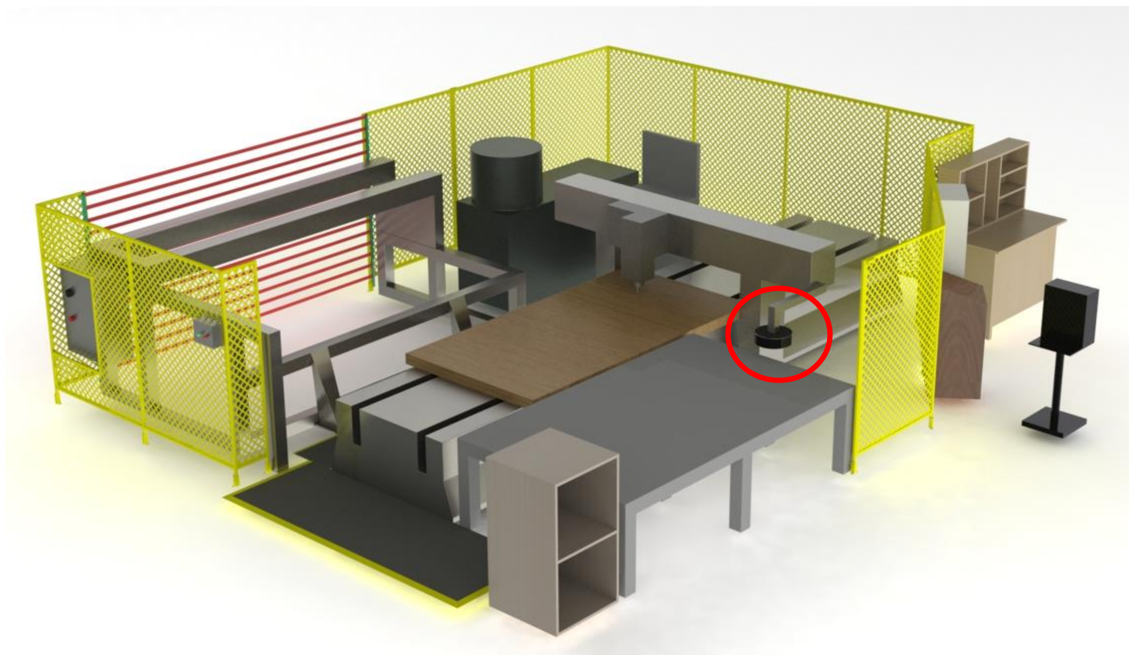

Figure 6: Isometric view of final design

After discussing the various details of Design A and B with the client, the main concern was the area around the tool changer, circled in Figure 6. The client needs the tool changer to be inaccessible while the machine is running, but easily accessible when the machine is off. The final concept, Design C, contains the addition of a physical barrier with an access door by the tool changer. The barrier is placed far enough from the tool changer that the operator cannot access that area while the door is closed.

3.1.1. Physical Barriers

To reduce the cost of the guarding system, physical barriers were applied in lieu of electronic sensors in areas where frequent access is not required. There are four main considerations when selecting physical barriers: the dimension, and location of the barrier and access doors, material used, and whether or not an interlock is required.

The first consideration is the dimension of the barriers. The height of physical barriers is 72 in, with an opening of six inches between the floor and the bottom of the barrier.

10-gauge welded wire mesh with 1 ¼ x 2 ½ in grid openings will be used to create the panels, and the barriers will be fastened to the ground with bolts. These are the minimum requirements listed in the CSA standard on implementing physical barriers. A standard panel is shown in Figure 7.

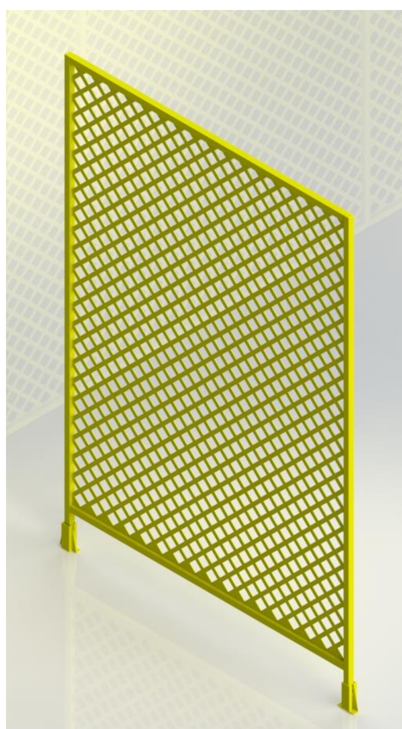

Figure 7: Mesh panel physical barrier

Physical barriers are placed around the machine's envelope, except the area in front of the material loader and the area around the CNC router table. To avoid changing the current machine position and extending too far beyond the machine's envelope, the barriers near the adjacent shelving units are placed on angles. Dimensioned drawings of the barrier panels are shown in Figure 8.

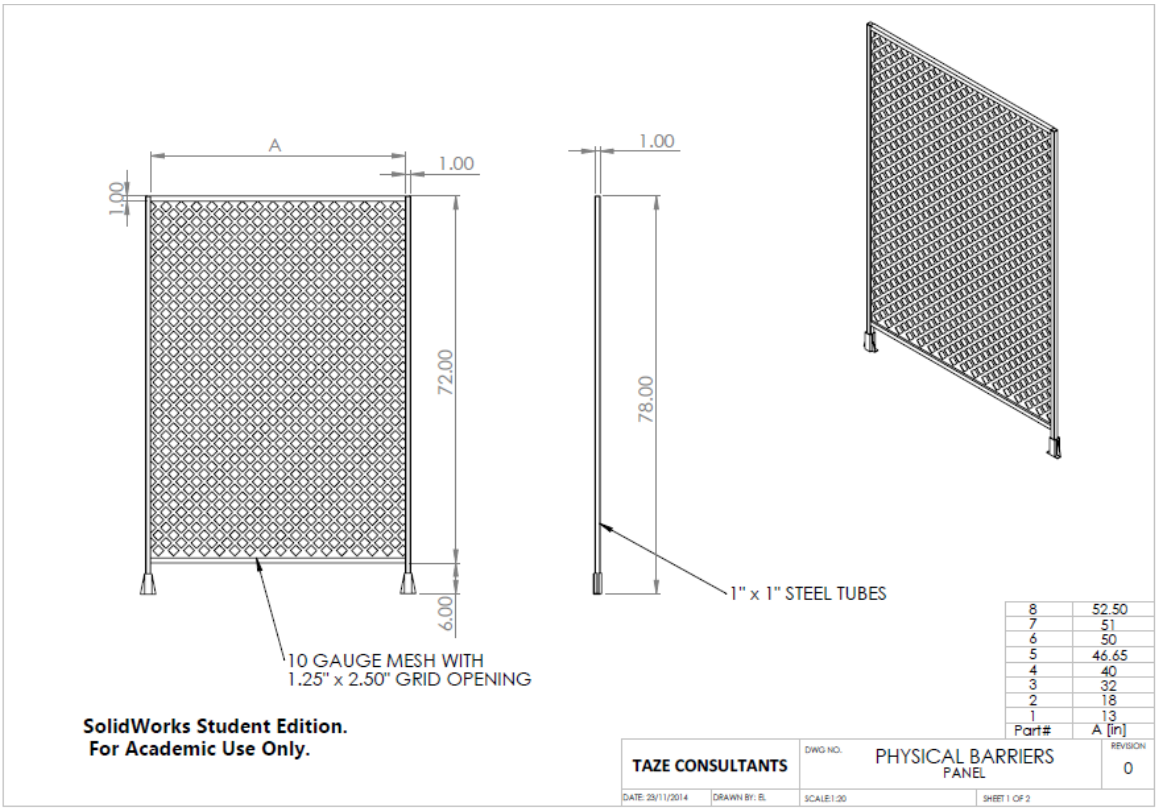

Figure 8: Physical barrier dimensions

The barrier beside the material loader is open at the existing power control panel. Since this panel contains an emergency stop button, the team decided to leave this area open for easy access. This barrier section will also hold the manual reset button for the floor mats. By placing the reset button on the exterior of the physical barrier, it ensures that the operator must be outside the machine's envelope before the machine can start. This portion of the barrier is shown in Figure 9.

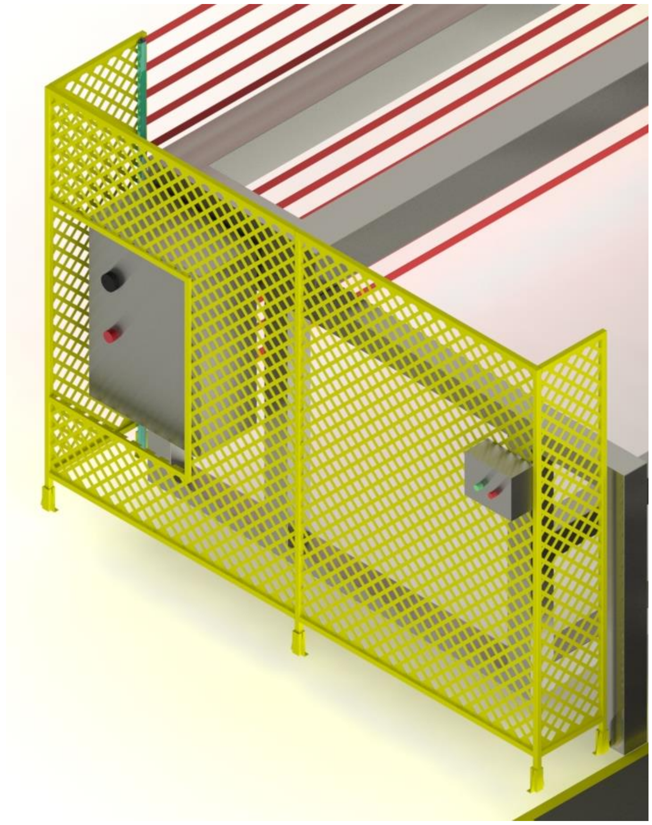

Figure 9: Physical barriers beside the material loader

Two access doors are incorporated into the guarding system. One is located beside the pump and is 50 in wide to allow easy access for any necessary maintenance. The other door is located in front of the tooling change area and is 48 in wide, which will let the operator easily change the cutting tool when the machine is not running. Figure 10 shows the access door near the vacuum pump.

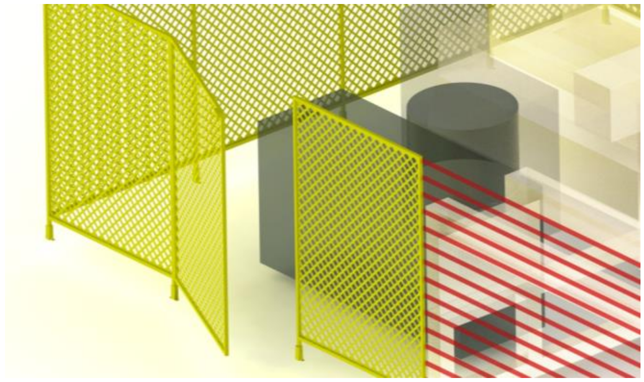

Figure 10: Access door by vacuum pump

Both of these access doors are equipped with an interlock switch that will shut down the machine if the door is open. Until the door is shut again, the machine will not be able to start. The access doors are created in a similar fashion to the other barrier panels. A dimensioned drawing of the access doors is shown in Figure 11.

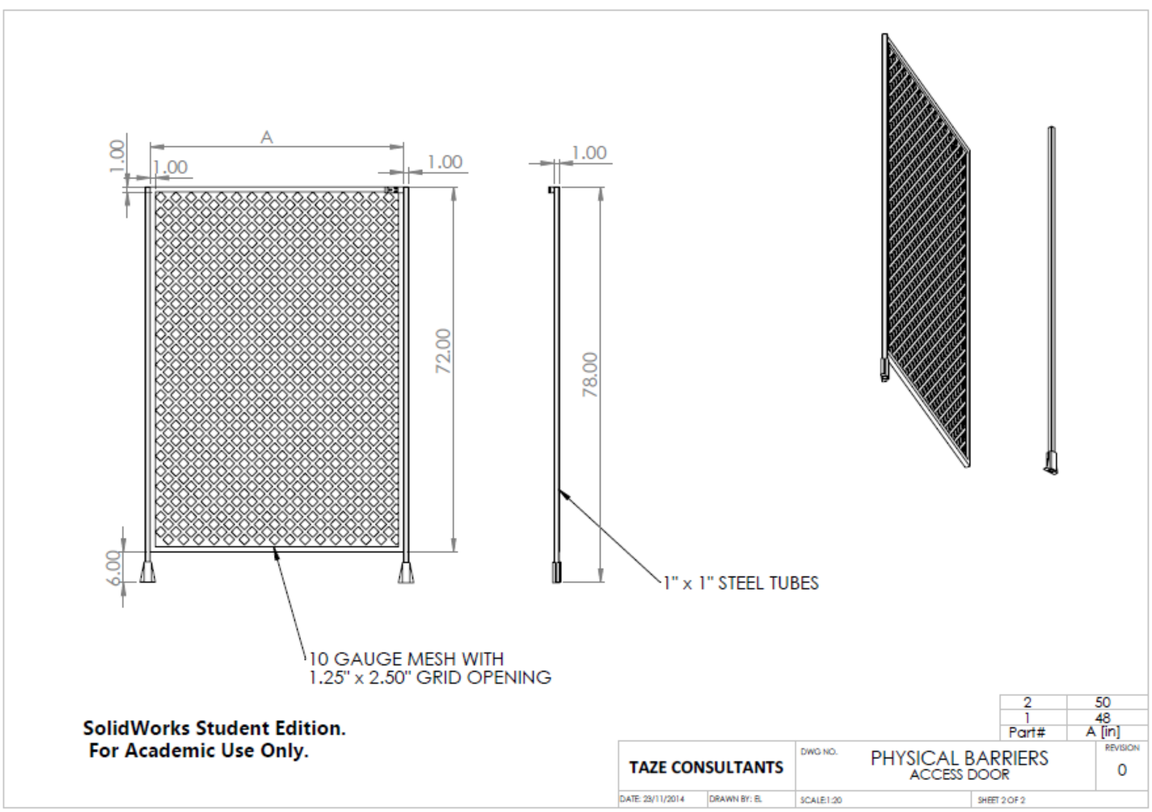

Figure 11: Access door dimensions

To ensure the physical barriers will protect the operators and bystanders from any airborne particles, the team performed a stress analysis on the barrier. 1010 carbon steel was chosen for the construction of the physical barriers because of its availability and strength. The following assumptions were made to aide in the calculation process.

Assumptions:

1. The speed of the cutting tool is 22000 rpm.
2. The influence of friction and air resistance on the airborne piece is negligible.
3. The airborne piece is assumed to be a 0.5x0.5x0.5 cm^3 wood.
4. The impact area of the piece of wood on the barrier is 0.5x0.5 cm^2
5. The airborne piece hits the barrier in a time period of 0.1 s.
6. The diameter of the cutting tool is 0.5 cm.
7. The density of the wood is 0.7 g/cm^3[1]

With these assumptions in mind, the team performed the stress analysis as follows:

Calculations:

- Weight of the piece:

$$\mathrm{m} = \mathrm{V} \times \rho = 0.5^3 \times 0.7 = 0.0875g = 8.75 \times 10^{-5} kg$$

- Speed of the airborne piece:

$$\mathrm{v} = \omega \times \pi \mathrm{D} = \frac{22000 \times 0.5\pi}{60} = 57.60 \, {}^{\mathrm{cm}}/_{s} = 0.576 \, {}^{\mathrm{m}}/_{s}$$

- Momentum of the airborne piece:

$$\mathrm{M} = \mathrm{m} \times \mathrm{v} = 8.75 \times 10^{-5} kg \times 0.576 \, {}^{\mathrm{m}}/_{s} = 5.04 kg \cdot {}^{\mathrm{m}}/_{s}$$

- Maximum stress caused by the airborne piece on the barrier:

$$\mathrm{P} = \frac{\mathrm{M}}{\mathrm{t} \times \mathrm{A}} = \frac{5.04 kg \cdot {}^{\mathrm{m}}/_{s}}{0.1\mathrm{s} \times (0.5 \times 0.5)\mathrm{cm}^2} = 2.016 MPa$$

- Applying a safety factor of 2:

$$P_{max} = P \times FOS = 2.016 MPa \times 2 = 4.032 MPa$$

The ultimate strength of 1010 carbon steel is 365 MPa, which is much higher than the maximum stress on the barrier [2]. Based on these calculations, it was concluded that the airborne pieces will not damage the barrier. Therefore, the team can confidently move forward with this choice in physical barriers.

3.1.2. Photoelectric Sensors

A light curtain was selected to be placed at the entrance of the material loader, as this area must be accessed frequently by a forklift. A type 4 light curtain sensor was selected as opposed to a type 2 sensor for this application [3]. Although the type 4 sensors are more expensive, they provide a more reliable sensor and are equipped with an automatic faulty circuit system which detects anything that goes wrong with the sensor. Utilizing the photoelectric sensor provides the operator with a safe working area and reduces the amount of space used.

The dimension of the chosen sensors is 1.5x1.5 x72 in. Figure 12 shows the infrared light beams created across the front of the material handler by the photoelectric sensor. In the event that one of these beams is broken, the material handler will be stopped. To ensure no one can reach over or under the sensor, the sensors are placed directly behind the barrier, and are the full barrier height. Placing the sensors behind the physical barriers lessens the chance of the sensors being damaged by material or machinery passing through this opening.

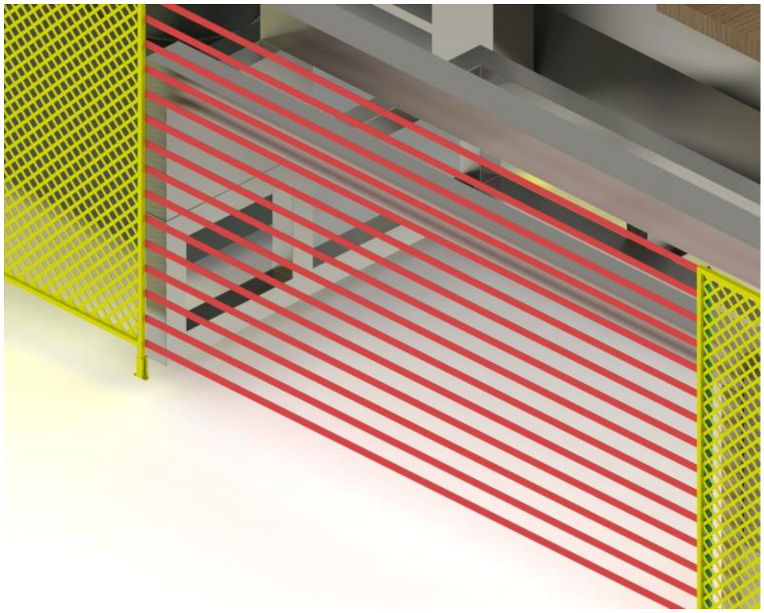

Figure 12: Photoelectric sensor used in front of material loader

The team can confidently move forward with this choice of photoelectric sensor since it effectively eliminates the risk of someone being pinched by any moving parts on the material handler.

3.1.3. Safety Floor Mat Sensors

Safety floor mat sensors will be configured in an 'L' shape, in between the material loader and in front of the CNC router table. The mats will be 17.85x132 in between the material handler and router table, and 36x108 in in front of the router table. This layout will require four separate mats to be placed side by side [4]. This layout is shown in Figure 13. The mats in front of the router table are bolted to the floor with angled ramps surrounding the area. These ramps serve two purposes: they keep the mats in place and they help reduce the chance of someone tripping on the edge of the mats. The mats in between the material loader and the router table are bolted to the floor with square trim. This trim is used where access to the sides of the mats is not required, such as in this case where the mats are against the machines. The mat width in front of the router table was chosen to ensure that the mats must be stepped on in order for someone to enter the danger zone. 36 in is a reasonable width because the average human stride is around 30 in. For operator convenience, the reset button will be located on the fencing adjacent to the router table.

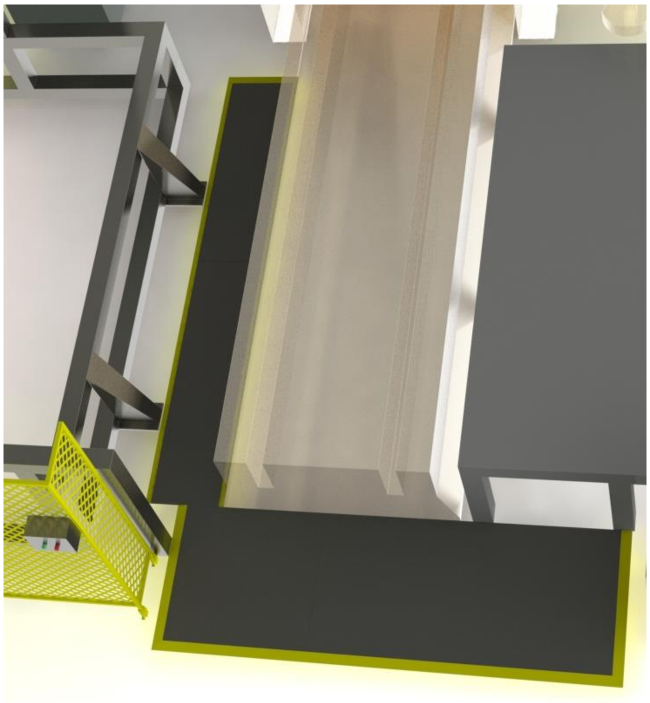

Figure 13: Safety floor mat layout

If someone steps onto the mat, the machine will automatically be stopped before injury can occur, and the machine will not start until no pressure is sensed by the mats and the reset button is manually pushed.

In order to minimize the amount of nuisance tripping of the floor mat sensors, the team looked at the required load that had to be sensed in order for the machine to be stopped. The safety floor mat sensors require a pressure of 66 lbs applied within a 3.15 in diameter circle, before being set off. Decor sometimes requires small intricate pieces to be cut by their CNC router. In these applications, small wood chippings or pieces have been known to fall between the material loader and the CNC router table which could cause the mats to stop the machine if they are over the pressure limit of the mats. This could lead to inefficiencies and lower quality of work being produced. By looking at a previous incident report provided by Decor, the team was able to determine the average size of the pieces being ejected from the router table. Knowing that the size of the particle from the incident report was 4x9x0.5 in and assuming that the density of the wood is 0.7 g/cm^3 [1], the following calculations were used to determine the average weight of these pieces.

- Volume of the piece

$$V = 4in\ X\ 9in\ X\ 0.5in = 18\ in^3$$

- Mass of the piece

$$m = \rho * V = 0.7g/cm^3 * 295cm^3 = 206g = 0.45lbs$$

Comparing the average weight from the cut offs and the weight required to set off the safety floor mats, the team can confidently say that placing safety mats in between the material loader and the router table will not decrease Decor's machining efficiency due to nuisance sensor tripping. For these reasons, the safety floor mat sensors were determined to be the best possible solution for safeguarding in the areas between the material handler and the CNC router table.

3.2. Cost Analysis

A procurement analysis of manufacturers and suppliers of all required parts was conducted to determine the cost of implementing the final design. For this project, the team was given a budget of $15,000. The expenditures can be broken into two categories: fixed and variable costs.

3.2.1. Fixed Costs

Physical barriers, photoelectric sensors, and floor mat sensors are used to build the safety guard. To reduce the shipping cost, all components for the physical barriers are quoted from a local supplier, General Metal. The photoelectric and safety interlock switches are quoted from Automation Direct, while the safety mat sensors are quoted from Motion Industries.

3.2.1.1. Physical Barriers

The metal for the physical barriers is supplied by General Metal, while the barriers are to be assembled by Decor's manufacturing team. The mesh style General Metal supplies is 10-gauge welded wire mesh with 1 ¼ x 2 ½ in grid openings. General metal also supplies the 1 in square tubing for the barriers frame. The subtotal for the physical barriers is $5,575.00.

The safety switch interlock system contains a switch, KP-200002, and a key, 140108 [6]. Two interlocks and two keys are required in this project. The interlocks are $38.50 each and the keys for the interlocks are $6.50 each. The subtotal for the safety interlock system $90.

3.2.1.2. Photoelectric Sensors

The photoelectric sensor is manufactured by Contrinex and supplied by Automation Direct. The sensor contains a sender, YBB-30S4-1800-G012, and a receiver, YBB-30R4-1800-G012. The chosen sensors are 72 in tall and are shown in Figure 14.

Figure 14: Photoelectric sensor [7]

A pricing summary on Automation Direct lists the sender and receiver as $795.00 and $942.00, respectively [7]. The subtotal of the photoelectric sensor is $1,737.00.

3.2.1.3. Safety Floor Mat Sensors

The floor mat sensors are manufactured by Bircher Reglomat and supplied by Motion Industries. The floor mat system used in this project is comprised of the following components:

- Four safety mats (36x72 in, 36x36 in, 17.85x72 in, and 17.85x60 in)
- One controller complete with a manual reset
- One 8.2 ohm resistor
- 17 ft of ramp side trim
- 22.5 ft of machine side trim

An example of the safety floor mats complete with ramp trim is shown in Figure 15.

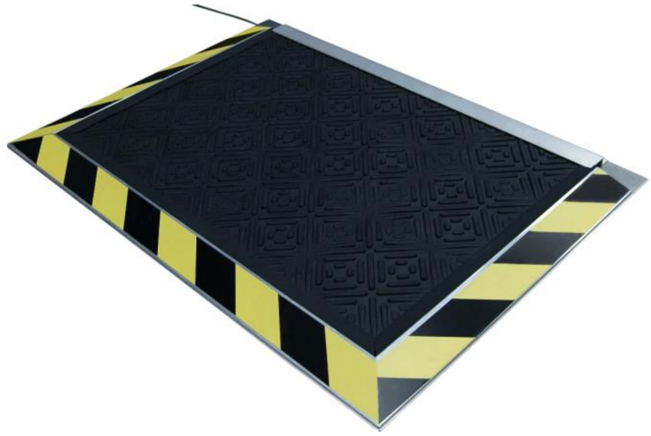

Figure 15: Safety floor mats by Bircher Reglomat [5]

The subtotal of these elements was quoted a $4,841.70 [4]. Therefore, the total fixed cost for this project was calculated to be $12,243.70.

3.2.2. Variable Costs

The variable costs include installation, wiring and machining costs. Based on the data from Decor, they have charge out rates of $60/hr, $30/hr and $60/hr for installation, wiring and machining respectively [8]. Using manufacturing guidelines for installation, this design will take the work shop at least 8 hours each to machine, wire and install. Using this value the subtotal of variable cost was calculated to be $1,213.00.

3.2.3. Total Cost

A summarized cost analysis is listed in TABLE IV. A buffer zone of 10 % of the total cost was added to cover any unexpected costs that may arise.

TABLE IV: COST BREAKDOWN

		Component	Quantity	Price ($)	Subtotal ($)
Component Cost	Floor Mat Sensor	CESM CB 3672 SAFETY MAT	1.00	1020.48	1020.48
		CESM CB 3636 SAFETY MAT	1.00	597.48	597.48
		ESM-21CB-17.875 X 60 CUSTOM SAFETY MAT	1.00	808.68	808.68
		ESM-21CB-17.875 X 72 CUSTOM SAFETY MAT	1.00	920.43	920.43
		ES-S RAMP TRIM	17.00	12.32	209.44
		ES-SZ MACHINE SIDE TRIM	22.50	7.71	173.48
		ESD3-06 24ACDC CONTROLLER	1.00	554.71	554.71
		ES-WID 8.2 OHM RESISTOR	1.00	0.00	0.00
	Photoelectric Sensor	YBB-30S4-1700-G012	1.00	795.00	795.00
		YBB-30R4-1700-G012	1.00	942.00	942.00
	Physical Barrier	Physical Bariers	1.00	5575.00	5575.00
	Interlock	KP-200002	2.00	38.50	77.00
		140108 interlock key	2.00	6.50	13.00
Variable Cost	Labor Cost		8 hr	60.00	480.00
	Installation Cost		8 hr	30.00	240.00
	Machine Cost		8 hr	60.00	480.00
Buffer		10% of total cost is added as a buffer			1312.42
Total					14436.63

The total cost of this project is estimated to be $14,436.63, including a 10% buffer, which is under the given budget of $15,000.

4. Design Justification

In order to measure the team's success in fulfilling the project requirements, a comparison between the original target specifications and the final design specifications was performed. This comparison is summarized in TABLE V.

TABLE V: COMPARISON OF TARGET AND FINAL SPECIFICATIONS

Metrics	Target Specifications	Actual
Implement physical barriers	> 45% of machine envelope	60% of machine envelope
Implement electronic sensors	≤ 1 sensor	2 sensors
Implement automated material handler	No operator required	No material handler implemented
Clearly identify danger zone	All danger zones are identified	All danger zones are identified
Clearly identify sensors	All sensors identified	All sensors identified
Implement barriers with accessibility	≥ 1 access point	2 Access points
Manual reset of sensors	All sensors with manual resets	Only safety floor mats have manual reset
Reduce the number of design components	< 4 guarding systems	3 guarding systems
Utilize company welder	Barrier assembly done in-house	Barrier assembly done in-house
Use off the shelf products	100% standard parts	90% standard parts
Utilize company electrician	100% of wiring done in-house	100% of wiring done in-house
Utilize local suppliers	100% of material found in Morden	Only barriers found in Morden
Use durable materials	All barriers made of steel	All barriers made of steel

To summarize, once the barriers are painted yellow to clearly identify them on the shop floor, all but one of the metrics with high priority will be met. The one metric that could not be met, was the implementation of an automated material handler due to its high cost.

5. Conclusion & Recommendation

Team 5: TAZE Consultants was tasked with improving the current guarding system for the KOMO CNC router machine at Decor's semi-custom manufacturing shop located in Morden.

The team first determined the customer needs, metrics and target specifications, as well as the constraints and limitations. Once these were determined, the team held an extensive internal and external brainstorming session on different methods of stopping an automated machine. After performing screening and scoring processes, and having a design review with the client, a final concept design was developed (Design C). This design was optimized to ensure it fully meets the CSA Standards and improves the overall operator and bystander safety.

The final design consists of three different guarding systems: physical barriers, photoelectric sensors, and safety floor mat sensors. Physical barriers are placed around the machine's envelope, except the area in front of the material loader and the area around the CNC router table. The barriers cover 60 % of the machines envelope and incorporate two access doors: one located beside the vacuum pump and one in front of the tool changer. The barriers help reduce the risk of air borne particles striking the operator or near bystanders, as well as stopping someone from entering the fenced-in area. The photoelectric sensors are placed on the backside of the physical barriers near the opening of the material loader. These sensors eliminate the risk of someone pinching themselves with the moving parts on the material loader. Safety floor mat sensors are placed in between the material loader and the CNC router table, and in front of the CNC router table. The safety floor mat sensors eliminate the risk of someone being in this area while the KOMO CNC machine is operating.

The costs for this project were split into fixed and variable costs. The fixed costs represent the components of the guarding system while the variable costs represent the manufacturing of the physical barriers, and the installation of the guarding system. The total cost for this project was found to be $14,436.63, which includes a 10 % buffer to account for any unforeseen expenses. The total cost is under the given budget of $15,000.

Since the guarding system meets the target specifications and the customer needs, TAZE consultants is confident this guarding system will eliminate the risk of injury from occurring while operating Decor’s KOMO CNC router machine.

6. References

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Appendix A: Weighted Customer Needs Matrix

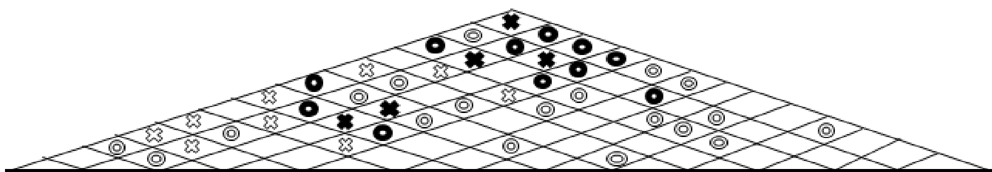
List of Figures

Section 1 of this report references the customer needs weighting matrix and the house of quality. Figure 1 shows the results obtained from the customer needs weighting matrix.

Customer Needs Weighting Matrix

Customer Needs		Guarding protects while machine is in current	Quality of the product is upheld	Machine operates efficiently with guarding	Meets CSA standards	Improves operator and bystander safety	Stays within budget	In house manufacturabilty	Last a long time	Easy to implement
	ID	A	B	C	D	E	F	G	H	I
Guarding protects while machine is in current position	A		B	C	D	E	F	A	A	I
Quality of the product is upheld	B			B	D	E	B	B	B	B
Machine operates efficiently with guarding in place	C				D	E	C	C	C	C
Meets CSA standards	D					D	D	D	D	D
Improves operator and bystander safety	E						E	E	E	E
Stays within budget	F							G	F	I
In house manufacturabilty	G								H	I
Last a long time	H									H
Easy to implement	I									
	Customer Need ID	A	B	C	D	E	F	G	H	I
	Occurrence	2	6	5	8	7	2	1	2	3
	Calculated Weight [%]	5.56	16.67	13.89	22.22	19.44	5.56	2.78	5.56	8.33

Figure 1: Customer needs weighting matrix



Target Specs Symbols

- ◎ Moderate Positive
- ● Strong Positive
- ✕ Moderate Negative
- ✖ Strong Negative

Relationship and Corresponding Value

Weak	-	(1)
Moderate	o	(3)
Strong	x	(9)

Metrics/ Target Specs

Customer Needs	Weight [%]	Implement Physical Barriers	Implement Electronic Sensors	Implement Automated Material Handler	Implement Barriers with accessibility	Clearly Identify Danger Zone	Manual Reset of Sensors	Utilize Local Suppliers	Use off the shelf products	Use Durable Materials	Clearly Identify Sensors	Utilize Company Welder	Reduce Number of Design Components	Utilize Company Electrician
Guarding protects while machine is in current position	5.56	x	x		x						-		-	
Quality of the product is upheld	16.67			o									-	
Machine operates efficiently with guarding in place	13.89	x	x	x			o				o		-	
Meets CSA standards	22.22	x	x	o	x	x	o		-		x			
Improves operator and bystander safety	19.44	x	x	x		x	o							
Stays within budget	5.56	x	o		o			x	x			x	o	x
In house manufacturabilty	2.78	x	x					-	o			x	x	
Last a long time	5.56	x	x	o						x	x	o		
Easy to implement	8.33	x	o									o	x	o
Evaluation		7.500	6.667	4.333	2.667	3.750	1.667	0.528	0.806	0.500	2.972	1.167	1.528	0.750
	Goals	> 45% of Machine Envelope	≤ 1 Sensor	No Operator Required	≥ 1 Access Point	All Danger Zones are Identified	All Sensors with Manual Resets	100% of Material found in Modren	100% Standard Parts	All Barriers Made of Steel	All Sensors Identified	Barrier assembly done in-house	< 4 Guarding Systems	100% of wiring done in-house
Technical Evaluation	5	X			C-X	X			C-X		X	X	C-X	C-X
	4		C				X	C		C-X				
	3	C	X				C	X			C			
	2													
	1			C-X		C						C		

Identification Symbols

New Design = X
Current Design = C

Figure 2: House of Quality

Appendix B: Project Management

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B1. Project management

In order for any project to be successful the team needed to create a project management plan as presented in this section. This plan is comprised of managing the project using two different tools. The first of which is the Work Breakdown Structure (WBS).

B1.1. Work breakdown structure

The project was structured to fall into three distinct phases with each phase having a clear deliverable. The WBS was produced to help the team identify key components of the project by breaking each phase into smaller manageable tasks. This WBS was a living document and changed as the project developed throughout the project life cycle.

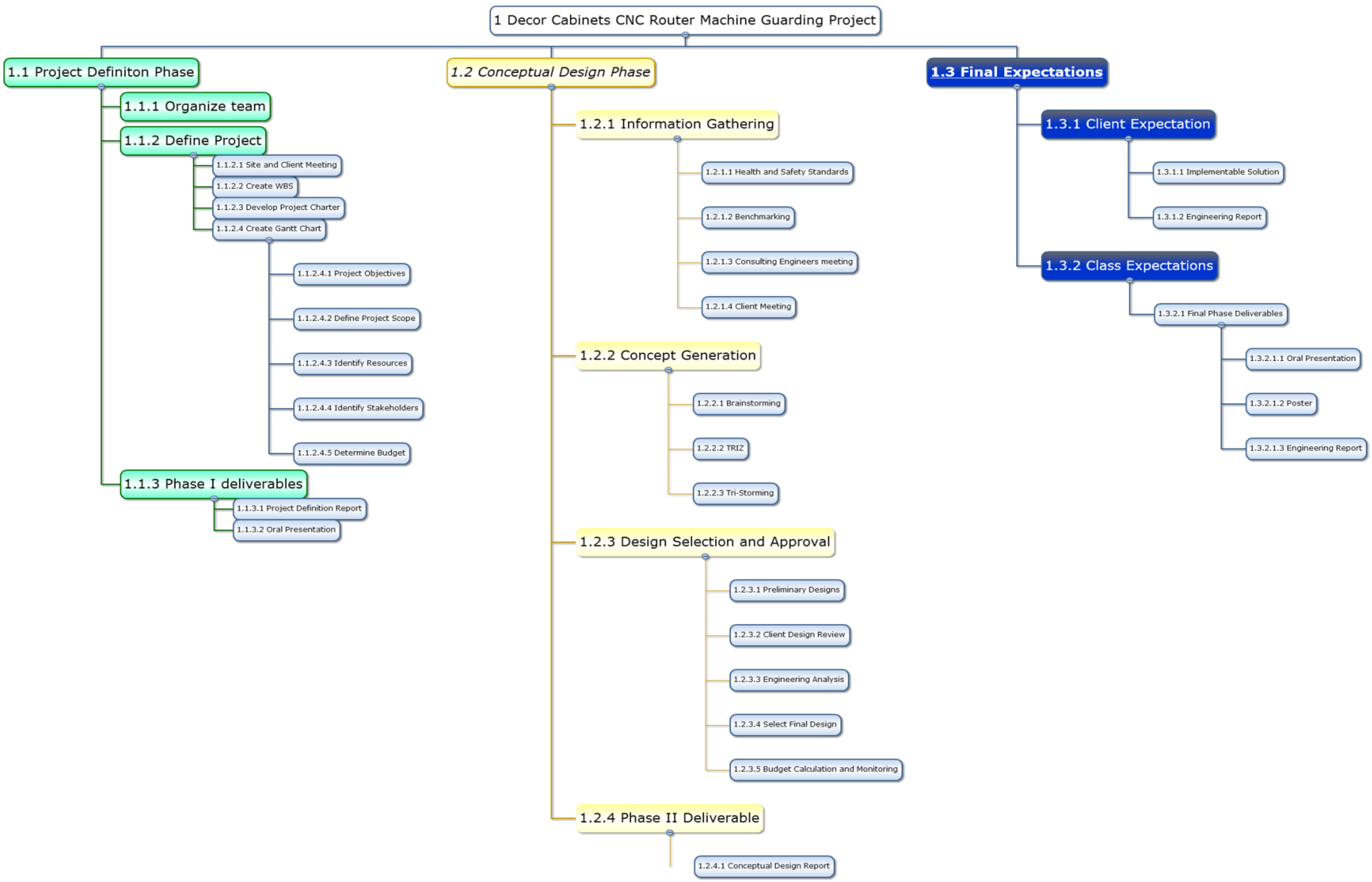

Figure 1: Work breakdown structure

B1.2. Gantt chart

The most important scheduling tool available to the team was a Gantt chart. The Gantt chart was made by the team to represent how each milestone of the project would be reached. This graphical tool was used to communicate to the faculty advisor and client how the team progressed in each stage of the project.

The Gantt chart is made up of three high level elements which are each phase of the projects as proposed by the course instructor. The team then used the deliverables as milestones and scheduled backwards based on the due dates. The duration of each element was determined using the most likely time the task would take to complete based on foreshadowing and previous experiences. The most critical tasks were given pessimistic durations to allow for unforeseen circumstances.

In the conceptual design phase a few alterations had to be made in the project schedule. The feedback from the first phase of the project directed the team to seek feedback from the course instructors prior to submitting the conceptual report. This meant that the team had to edit each other's work prior to October 21, 2014 as initially planned. The due date was moved to October 20, 2014 in order to submit the draft to the technical communications specialist for October 21, 2014. These changes were incorporated into the team's Gantt chart. This adjustment did not cascade to the final design phase of this project. The final phase had a peer feedback component which the team scheduled for and this led to the final report being completed November 23, 2014. This gave the team enough time to seek more feedback from the technical communications specialist and faculty advisor.

Task Name	Start Date	End Date	Duration	Predecessors
Décor Cabinets	08/09/14	03/12/14	87	
Phase I - Project Definition Phase	10/09/14	28/09/14	19	
Meet and Organize Team	10/09/14	10/09/14	1	
Team Meeting 1	10/09/14	10/09/14	1	
Define Project	13/09/14	18/09/14	6	
Team Meeting 2	13/09/14	14/09/14	2	
Develop Project Charter	13/09/14	14/09/14	2	
Create Project Schedule	13/09/14	14/09/14	2	
Site Visit and Client Meeting	15/09/14	17/09/14	3	6
Identify Project Deliverables	15/09/14	15/09/14	1	
Identify Resources	15/09/14	15/09/14	1	
Identify Stakeholders	15/09/14	17/09/14	3	
Define Project Scope and Objectives	15/09/14	17/09/14	3	
Determine Budget	15/09/14	15/09/14	1	
Team Meeting 3	18/09/14	18/09/14	1	9
Create WBS	18/09/14	18/09/14	1	
Identify Phase I Written Report and Oral Presentation Requirements	18/09/14	18/09/14	1	
Assign Tasks for Phase I Deliverables	18/09/14	18/09/14	1	
Phase I Deliverables	19/09/14	28/09/14	10	17
Project Definition Report - Draft	19/09/14	22/09/14	4	
Project Charter and Project Definition Report Sent to Client and Advisor For Feedback	19/09/14	22/09/14	4	
Project Definition Report - Final	23/09/14	26/09/14	4	21
Create Oral Presentation Slides	23/09/14	25/09/14	3	21
Practice Oral Presentation	26/09/14	28/09/14	3	23
Submit Project Definition Report	29/09/14	29/09/14	0	24
Oral Presentation	29/09/14	03/10/14	5	24
Peer Evaluation 1	03/10/14	03/10/14	1	
Meeting Minutes	24/09/14	24/09/14	1	
Gannt Chart	24/09/14	24/09/14	1	
Log Book	24/09/14	24/09/14	1	
Phase II - Conceptual Design Phase	04/10/14	24/10/14	21	
Concept Generation	04/10/14	08/10/14	5	
Generate Designs	04/10/14	05/10/14	2	26
Evaluate Design Alternatives	06/10/14	08/10/14	3	33
Select Final Design	09/10/14	14/10/14	6	34
Final Design Sent to Client and Advisor For Feedback	09/10/14	14/10/14	6	
Identify Phase II Written Report Requirements	15/10/14	15/10/14	1	
Assign Tasks for Phase II Deliverables	15/10/14	15/10/14	1	36
Phase II Deliverables	08/10/14	24/10/14	17	
Meeting Minutes	08/10/14	08/10/14	1	
Gannt Chart	08/10/14	08/10/14	1	
Log Book	08/10/14	08/10/14	1	
Conceptual Design Report - Draft	16/10/14	19/10/14	4	38
Conceptual Design Report - Edit each other's work	20/10/14	21/10/14	2	43
Conceptual Design Report - Final	22/10/14	24/10/14	3	44
Submit Conceptual Design Report	24/10/14	24/10/14	0	

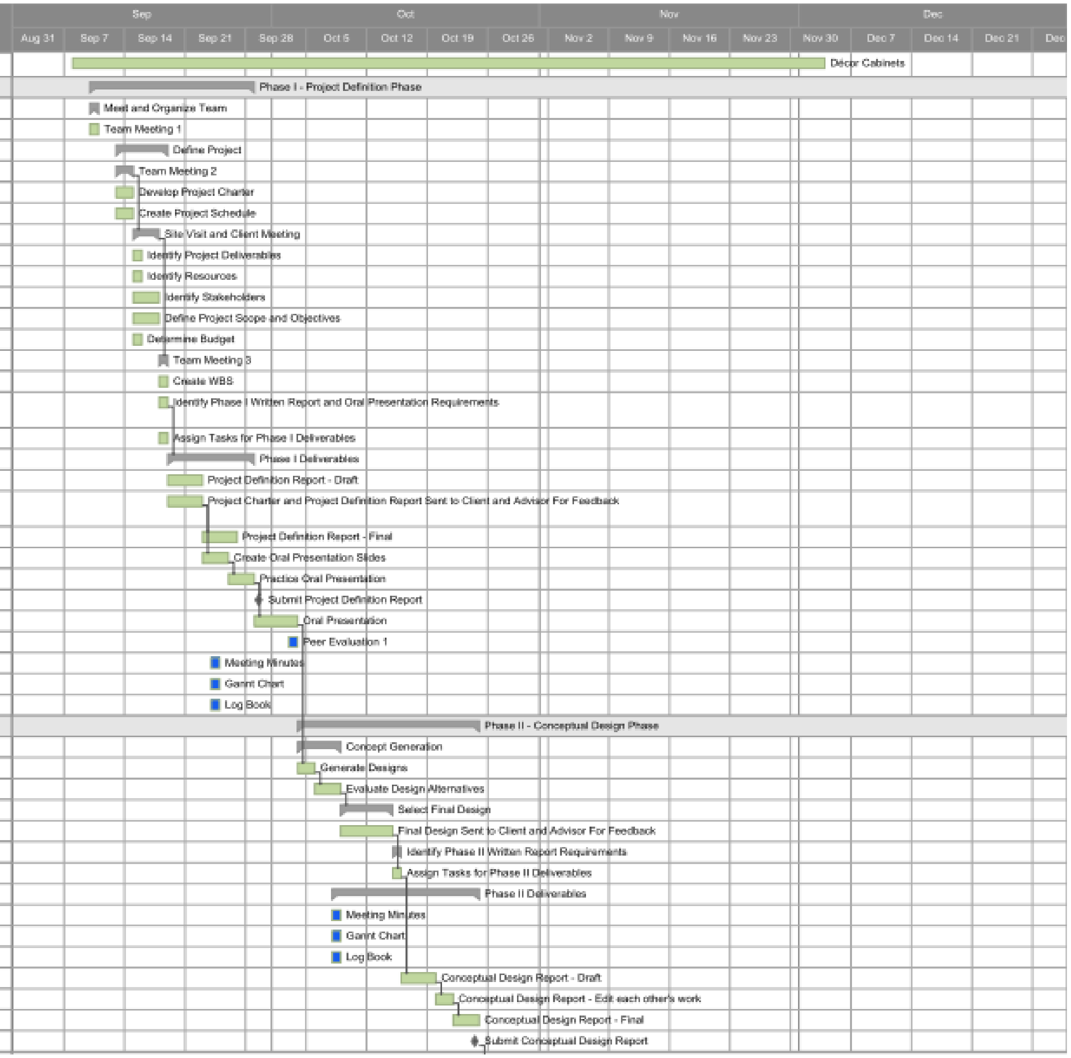

Figure 2: Phase 1 & 2 Gantt chart

Final Phase	25/10/14	02/12/14	39	
Identify Final Phase Requirements	25/10/14	25/10/14	1	42
Final Phase Report Requirements	25/10/14	25/10/14	1	
Oral Presentation Requirements	25/10/14	25/10/14	1	
Poster Presentation Requirements	25/10/14	25/10/14	1	
Assign Tasks for Final Phase Deliverables	25/10/14	25/10/14	1	
Final Phase Report Requirements	26/10/14	30/11/14	36	
Final Phase Report - Draft	26/10/14	15/11/14	21	48
Final Phase Report - Peer Critique	24/11/14	26/11/14	3	
Final Phase Report - Final	21/11/14	30/11/14	10	53
Submit Final Phase Report to Client For Approval	16/11/14	20/11/14	5	50
Meeting Minutes	29/10/14	29/10/14	1	
Gannt Chart	29/10/14	29/10/14	1	
Log Book	29/10/14	29/10/14	1	
Peer Evaluation 2	29/10/14	29/10/14	1	
Mid-November Deliverables	19/11/14	19/11/14	1	
Meeting Minutes	19/11/14	19/11/14	1	
Gannt Chart	19/11/14	19/11/14	1	
Log Book	19/11/14	19/11/14	1	
Oral Presentation Requirements	16/11/14	01/12/14	16	
Create Oral Presentation Slides	16/11/14	25/11/14	10	50
Practice Oral Presentation	26/11/14	01/12/14	6	63
Meeting Minutes	26/11/14	26/11/14	1	
Gannt Chart	26/11/14	26/11/14	1	
Log Book	26/11/14	26/11/14	1	
Poster Presentation	26/10/14	01/12/14	37	
Create Poster	26/10/14	12/11/14	18	47
Find Critique	13/11/14	22/11/14	10	69
Finalize Poster	23/11/14	01/12/14	9	70
Meeting Minutes	05/11/14	05/11/14	1	
Gannt Chart	05/11/14	05/11/14	1	
Log Book	05/11/14	05/11/14	1	
Peer Evaluation 3	01/12/14	01/12/14	1	
Submit Final Report	01/12/14	01/12/14	0	52
Oral Presentation	02/12/14	02/12/14	0	64
Poster	02/12/14	02/12/14	0	71

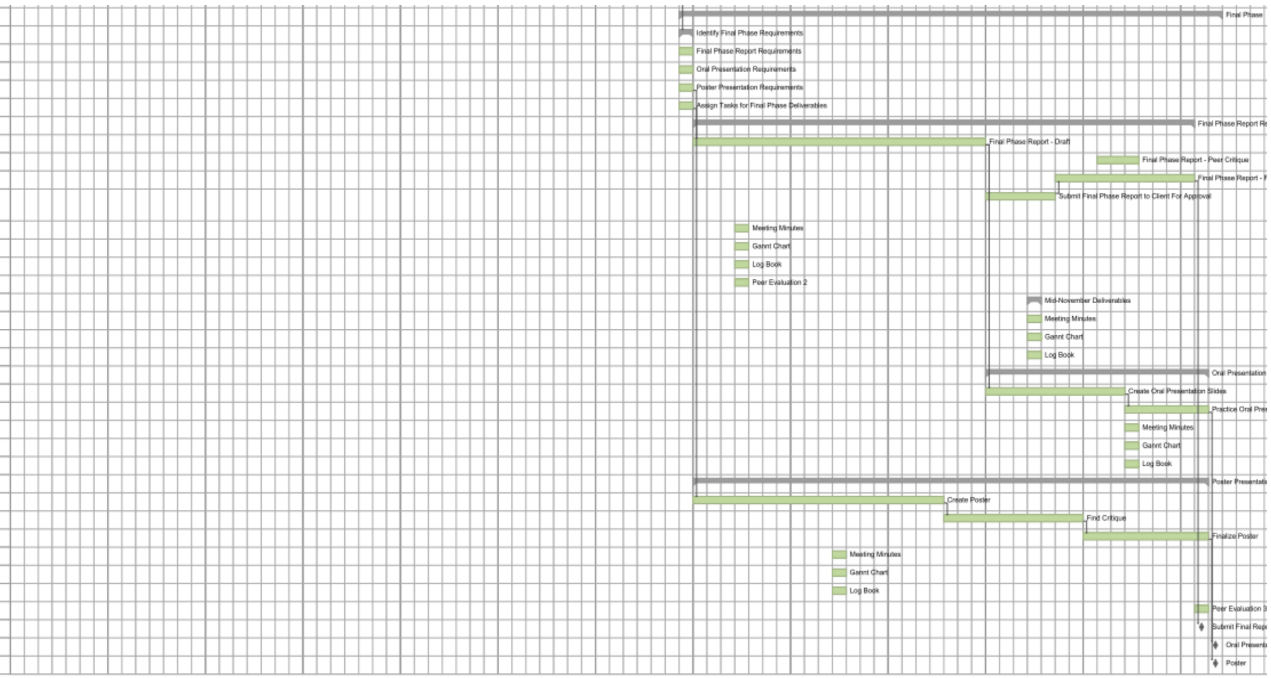

Figure 3: Phase 3 Gantt chart

Appendix C: Supplier Quotations

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C1. Floor Mat Quote

The floor mats are bought from Motion Industry, which is a dealer for Bircher Reglomat. The quote list is shown as below. The subtotal for floor mat is $4841.70.

E-mail Address:

Ship To:

MOTION CANADA VISA

Phone:

Note: This estimate is valid for 30 days from the date shown below. Prices quoted are for quantities shown. Stock is subject to prior sale. MTO quantities considered complete 10% under/over unless noted.

Quote Information

Customer PO#: TRAVIS DEFOORT Quote Number: MB21-299303
Release No: Date: 11/13/2014
F.O.B:
Terms: . CRDTCD
Delivery: STOCK UNLESS NOTED

4-5 DAYS TO SHIP
FOB SCHAUMBURG, IL

Qty Description

1.0 BIRCHER RE CESM CB 3672 SAFETY MAT
36" X 72"
Item No..........: 99999999
Cust Stk No .....:
Price...........: 1020.480 1020.48
Delivery Date ...:

1.0 BIRCHER RE CESM CB 3636 SAFETY MAT
36" X 36"
Item No..........: 99999999
Cust Stk No .....:
Price...........: 597.480 597.48
Delivery Date ...:

1.0 BIRCHER RE ESM-21CB-17.875 X 60 CUSTOM SAFETY MAT
17.875" X 60"
Item No..........: 99999999
Cust Stk No .....:
Price...........: 808.680 808.68
Delivery Date ...:

1.0 BIRCHER RE ESM-21CB-17.875 X 72 CUSTOM SAFETY MAT
17.875" X 72"
Item No..........: 99999999
Cust Stk No .....:
Price...........: 920.430 920.43
Delivery Date ...:

17.0 BIRCHER RE ES-S RAMP TRIM
Item No..........: 99999999
Cust Stk No .....:
Price...........: 12.320 209.44
Delivery Date ...:

22.5 BIRCHER RE ES-SZ MACHINE SIDE TRIM
Item No..........: 99999999
Cust Stk No .....:
Price...........: 7.710 173.48
Delivery Date ...:

1.0 BIRCHER RE ESD3-06 24ACDC CONTROLLER

Item No..........: 99999999
Cust Stk No .....:
Price............: 554.710 554.71
Delivery Date ...:

1.0 BIRCHER RE ES-WID 8.2 OHM RESISTOR
Item No..........: 99999999
Cust Stk No .....:
Price............: 0.000 0.00
Delivery Date ...:

COMPLIMENTARY W/ ORDER

SUBTOTAL	4284.70
FREIGHT*	0.00
TAX	557.01
TOTAL**	4841.70

----
* Freight amounts are subject to change based on package weight.
** Total excludes applicable taxes and special freight charges.

You may review all of your present and past orders or quotes online at http://www.MotionIndustries.com

C2. Physical Barrier Quote

The metal for the Physical barriers is supplied by General Metal. The quote is based on a 3-D CAD model that was supplied to General Metal. The subtotal is $5575.00.

General Metal Fabrication Ltd

Phone:
Fax:

Quote Number: 1412 **Quote** **Page:** 1 of 1

Quote To:

Cash Sale
Canada

Phone: ONE Fax:

Date 21-Nov-2014

Expires: 21-Dec-2014

Reference:

Sales Person: Herman Giesbrecht

Fax:

Canadian Dollar

Line	Part	Description	Rev	Drawing
1	1412	Fence		

Lead Time

Price based upon supplied 3D cad files
Frames HSS 1" x 1" x .100"
Mesh, Wire, Welded, 2 X 2 X .125 Wire
Post to frames would be a bolted connection.
Sand blasted and powder coated
FOB Our Shop
All Taxes Extra
Price is estimated and would be confirmed upon final design.

Quantity	Unit Price	Discount %	Net Price
1.00 Each	5,575.00 /1		5,575.00 *CAD$*

QuotForm:001:00