Value Engineering Design of Shower Curb Manufacturing Line

Presented to:

Schluter Systems

Authored by:

Xiaoqi Zhang, Marvin Bertin, Julian Ashley, Muhammad Rahim, Corey Hill

Consulting Engineer:

Josef Slanik

Value Engineering | McGill University | December 12, 2014

Contents

Executive Summary

Objectives

This project is based on the design and development of a manufacturing line for Schluter Systems Canada. Schluter's new product, the 'Kerdi-board shower curb', is currently hand-made but the company requires a proper manufacturing line to enable mass production at the targeted 100,000 units per year.

Solution

The project proposes specific combinations of equipment for the manufacturing process as shown in the table below. These combinations have been selected based on maximum total value and minimum total cost. It was found that the best value comes from shipping the product flat. However, if Schluter decided to sell the product folded, there was value in this as well. Therefore, the Best Value and Best Cost combinations were provided for both a folded product and flat product.

Production Stage	Best Value Folded	Best Cost Folded	Best Value Flat	Best Cost Flat
Slicing	Oscillating Blade	Abrasive Wire	Oscillating Blade	Abrasive Wire
Groove Cutting	5016 CNC Router	3000 Series	5016 CNC Router	3000 Series
Adhesive	Hot Melt	Hot Melt	T-626 Tape	T-626 Tape
Folding and Packaging	Gradual Glide + Zinglu Machine	Mechanical Arm + Zinglu Machine	Zinglu Machine	Zinglu Machine

Results

The selections above provide the optimal design for the manufacturing process that will yield the highest value to the company as well as ensure total satisfaction for the end users.

Acknowledgements

We, the Value Engineering team, would like to express our gratitude towards Mr. Josef Slanik, who served as our consulting engineer, and whose guidance and continuous support proved to be invaluable for this project.

We would also like to thank Ms. Lucie Parrot, eng., CVS, Professor Paul Joseph Zsombor-Murray and Professor Vince Thomson, for introducing us to the world of Value Engineering and teaching us the principles so that we may continue to apply them throughout our careers.

We are also grateful to McGill University for providing us with the opportunity to work on a real industrial problem in this course which was a very challenging and rewarding experience for all of us.

Team Members

This is a picture of our project team at the McGill presentations hosted by Canadian Society of Value Analysis (CSVA).

From left to right, the team members are:

Xiaoqi Zhang

Julian Ashley

Muhammad Rahim

Corey Hill

Marvin Bertin

Introduction

Value Engineering

Value Engineering is a systematic and structured analysis that improves projects, products and processes. It does so by identifying and selecting the ‘’best value’’ alternatives for designs, materials, processes and systems. Technically, the term ‘Value’ denotes the ratio of ‘Satisfaction’ to ‘Cost’ (for a particular product, process or system).

$$Value = \frac{Satisfaction}{Cost}$$

Hence, the objective of performing Value Analysis is to extract the highest satisfaction (by meeting all customer needs) at the lowest overall cost.

Client and Background: Schluter Systems and the New Product

Schluter Systems is a major manufacturer of products for the tile industry. The Schluter Shower System consists of prefabricated shower substrates, containing a shower base and shower curb, that are intended to provide a light-weight, easy-to-install alternative to mortar bases. The shower base and curb are made of a new universal substrate material devised by Schluter named ‘Kerdi-Board’. Essentially, this ‘Kerdi-Board’ is made of an extruded polystyrene foam core with reinforcement layers and fleece webbing on both sides for easy anchoring in thin-set mortar. Schluter has a new shower curb product which is a single, foldable piece and simple for the customer to install. Schluter wishes to design a manufacturing line that will mass-produce this new product in the most cost-effective, efficient and reliable manner.

Methodology

In order to come up with a working final design, there were many factors that needed to be considered. We needed a clear and organized way of determining the challenges we would face and to come up with effective solutions in order to overcome them. This was accomplished starting with a Functional Analysis.

Functional Analysis

Several steps in the Functional Analysis were taken in order to analyze the gathered information efficiently. These steps included the Information phase, Identification of Functions, Flexibility Chart, Functional Diagram and Environmental Analysis. While keeping the objectives in mind, these steps gave us a platform on which to build and proceed with our ideas in the following phases. During these phases, the team members were encouraged to speak up freely without fear of criticism or dismissal.

Information Phase:

For every project, the first step that must be completed is gathering information. During the information phase, we made a simple list of technical, economic, social and legal aspects of the production of the Kerdi-board that would need to be analyzed in detail. This gave us an idea of all of the factors we must consider for the final design of our manufacturing process and paved the way for the rest of the analysis.

-*Technical:* Speed of production, specs of product, type of cutting blades, hours of the factory, holding the board, adhesives, shipping, packaging, life-span

-*Economic:* Cost of materials, capital costs, operating costs, employees, packaging, down-time

-*Social:* Ease of use, shower, type of glue, disposal, scrap, price

-*Legal:* Safety, waste

Identifying Functions:

We then made a list of the various primary and secondary functions that the product and the manufacturing must fulfill. The primary functions are the main tasks the product and the manufacturing are designed to perform. The secondary functions are less important yet they still help the product and the manufacturing better perform their purpose. The product and the manufacturing process must satisfy the functions listed below as “primary” and “secondary”.

Product:

Primary:

Contain water

Secondary:

Repel water

Support weight

Have easy installation

Manufacturing:

Primary:

Glue Pieces

Cut grooves

Separate pieces

Fold pieces

Have efficient packaging

Hold pieces

Secondary:

Maintain quality

Increase productivity

Minimize down-time

Be maintained easily

Increase value

Maintain safety

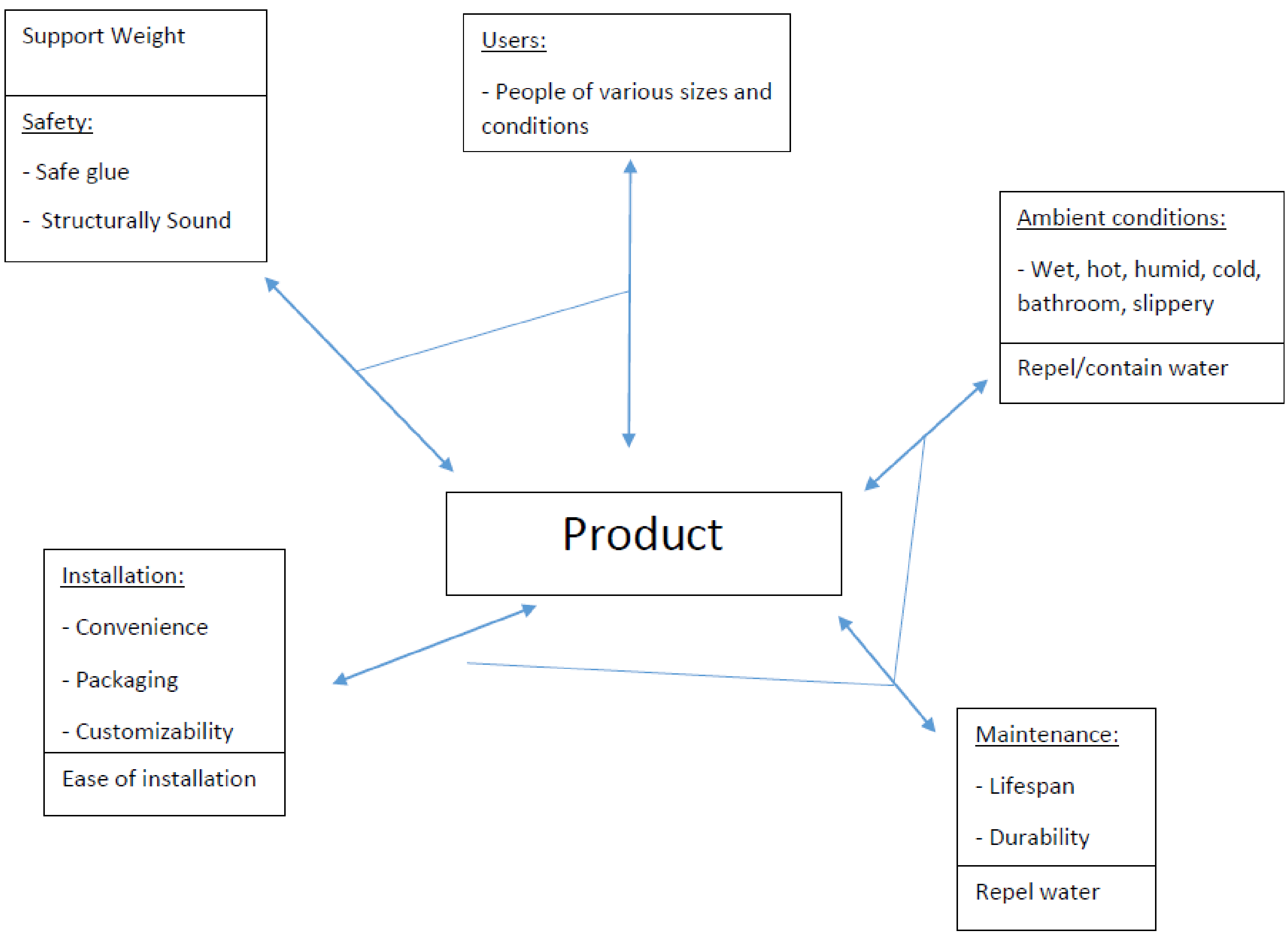
Minimize waste

Comply with standards

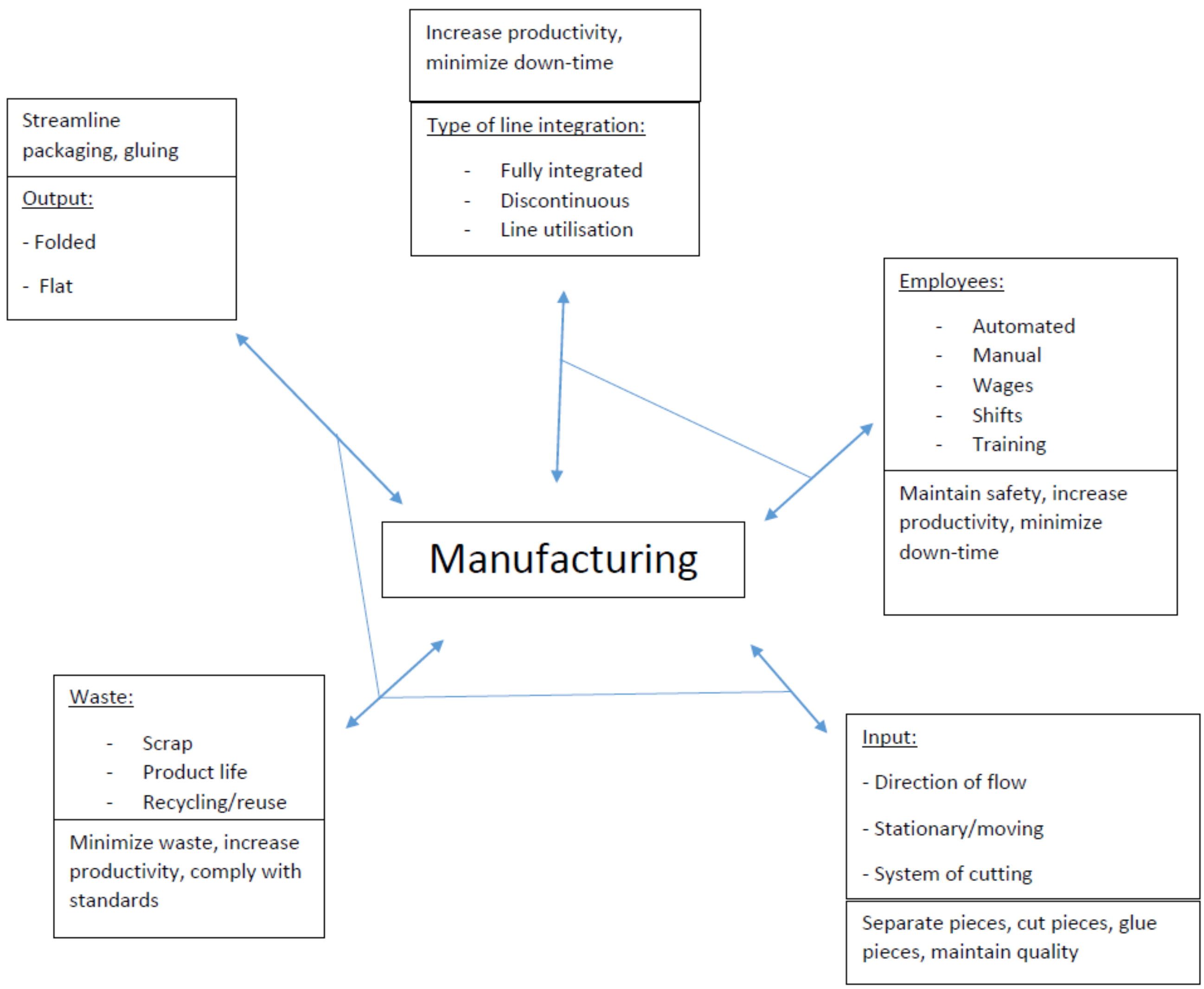
Environmental Analysis:

To further build on the functions, an environmental analysis on the product and the manufacturing was used. This method made it easy to see the functions and how they affect their surroundings. The product and the manufacturing are placed in a sort of a “black box” in the center and the functions and the aspects of the environment affected are listed together in the surrounding boxes. The relations between the different functions and surroundings are delineated by the blue line connecting the arrows.

Product Environmental Analysis:



Manufacturing Environmental Analysis:



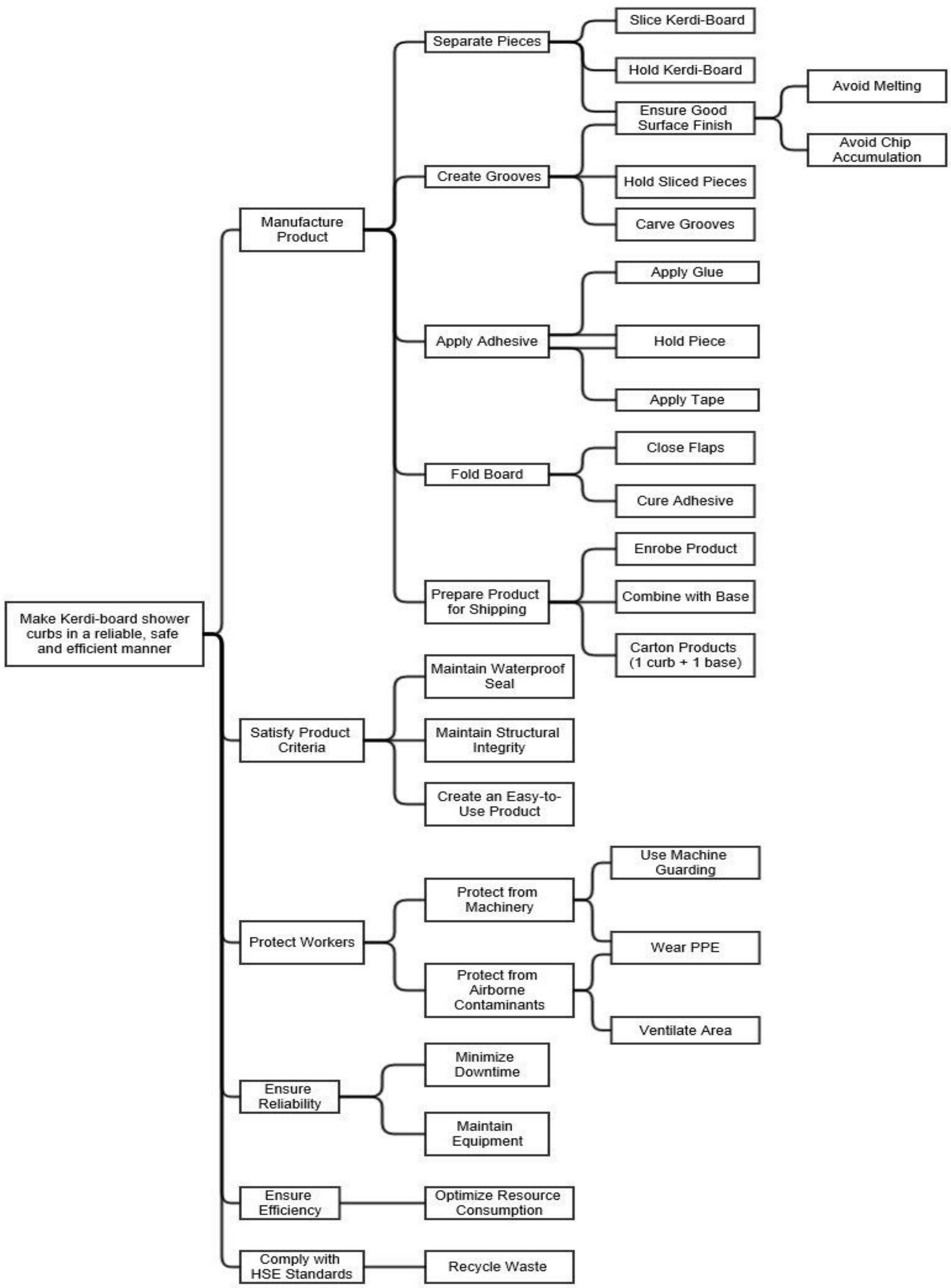
Flexibility Chart:

Next, we constructed a flexibility chart. This helped us put into perspective the strictness of all of the requirements which in turn helped us gage which aspects to prioritize. We listed each function, the criterion of how the function is measured, a level of acceptability and a flexibility rating with f3 being the most flexible and f0 being the most rigid.

Function	Criteria	Level	Flexibility
Slice Kerdi board	Dimensions	width: 6 inches 4.5 inches 6 inches = 16.5 inches; Length: 4 feet	f0
Hold Kerdi board	Force	Sufficient for all processes	f0
Avoid melting	Temperature	Below melting temp	f0
Avoid chips accumulation	Surface roughness	Adequate foir adhesives	f1
Carve grooves	Groove angle	90 degrees	f0
Hold pieces while carving	Force	Sufficient for carving	f0
Apply glue	Adhesive force	Maintain structural integrity	f0
Apply tape	Adhesive force	Maintain structural integrity	f0
Close flaps	Angle	90 degrees	f0
Cure adhesive	Drying time	Fast	f1
Hold piece while folding board	Force	Adequate for folding	f0
Enrobe product	Coverage	100%	f0
Combine with base	Number of parts	One base one curb	f0
Carton products (base + curb)	Closed and sealed	100%	f0
Use machine guarding	CSA Standard	Fully comply	f0
Wear PPE	CSA Standard	Fully comply	f0
Ventilate area	PPM Measurement	Safety standard	f0
Minimize downtime	Availability (uptime/totaltime)		f2
Maintain equipment	life time / expected life	100%	f2
Optimize resource consumption (energy, materials, labor)	Cost of production per unit		
Recycle waste	$ per ton of waste		
Maintain waterproof seal	Water permeability	0%	f0
Maintain structural integrity	Ultimate strength of the structure (Mpa)		f0
Create easy-to-use product	Time of installation		f3

Functional Diagram

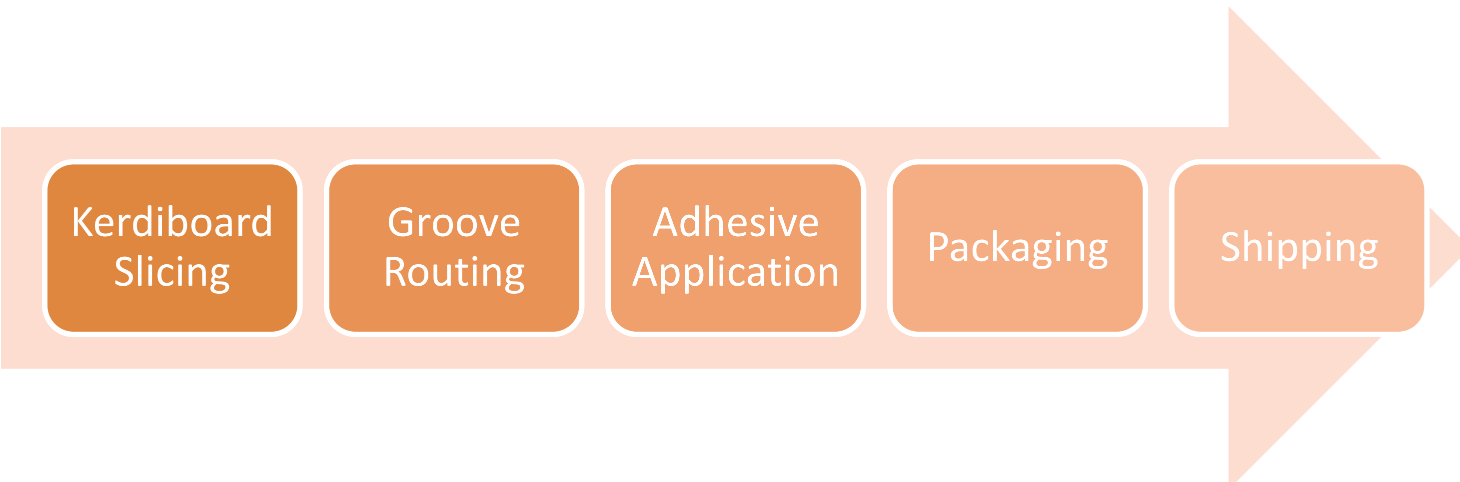
With this method, the functions were organized in a tree where the functions become progressively specific as they branch out. This made it easier to see the relationships between various functions, their relative importance and in which order they must be carried out. The functions towards the right must be carried out prior to the ones to the left.



Concept Generation

Creativity Phase

Our manufacturing process receives an input of a large piece of Kerdi-board (dimensions 96”x48”) which is processed and outputted as the final shower-curb product. The manufacturing process is essentially divided into the following segments:



In the Creativity phase of the project, the team focussed on brainstorming various conceptual alternatives for each stage of the manufacturing process, and conducted extensive research to gather information about the various options to better assist in the final selection. During this concept generation phase, we ensured that all ideas were brought forth onto the table without any barriers or restrictions. The main idea behind brainstorming is to allow ideas to flow freely without receiving any criticism so that all the potential solutions can be looked at. The way we achieved this was by deploying a strategy known as ‘brain-writing’. We passed around different sheets of paper, each sheet for a specific part of the process, and we took turns writing down our ideas one by one. This methodology allowed us to generate a wide range of possible solutions for each manufacturing step, as well as possible options for waste management, all of which were written down.

Brainstorming Results

The following are the results from the brainstorming process:

Kerdi-Board Slicing:

1. Drop and draw knives
2. Guillotine
3. Rotating blade (with grinder + cleaner)
4. Hot wire
5. Abrasive wire
6. Lasers
7. Water jet
8. Extruder
9. Rotating saw (width creates more scrap)
10. Vibrating tool

Groove routing:

Tools

1. Pair of angled knives (stationary vs. moving)
2. Facility to cut both grooves at the same time
3. Fold and cut (with wire or blade)
4. Extruder (broaching)
5. Vibrating tool

Chip removal

1. Blowing air
2. Brushing
3. Vibration
4. Flipping it over
5. Vacuum

Holding

1. Contact rollers (moving board)
2. Fixed with pallet (moving board)
3. Suction surface (stationary board)

Adhesive application:

Glue

1. One side vs. both sides
2. Glue spreader vs. continuous flow
3. Spray adhesive
4. Chemical reaction spray

5. Heating surface
6. Infrared heating
7. Staples

Tape

1. Stamp tape
2. Roller tape
3. Tape and fold
4. Tape while reverse folded
5. All-in-one tool (cut, blow, tape/glue)

Folding:

1. The tunnel with rollers
2. Gradual guide
3. Mechanical arms
4. Drop down guide
5. Accumulator
6. Curing in box

Packaging:

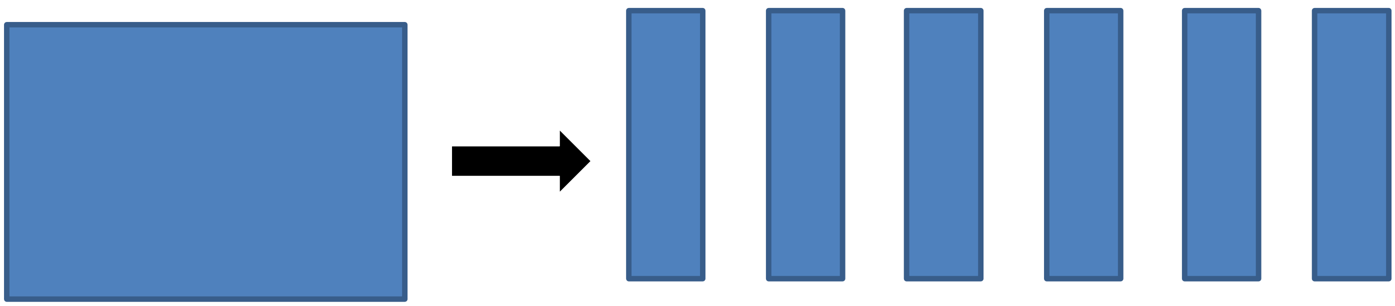
1. Folded board (combined with shower base)
    - *Box dimension: 28.5"x48"x6" = 8208 in3*
2. Unfolded board (combine with platform)
    - *Box dimension: 24"X48"X5" = 5760 in3*

All of the above are the results from our initial brainstorming session. We then conducted extensive market research to gather knowledge about which options are feasible for the purposes of our project. This allowed us to narrow down our conceptual alternatives to a select few.

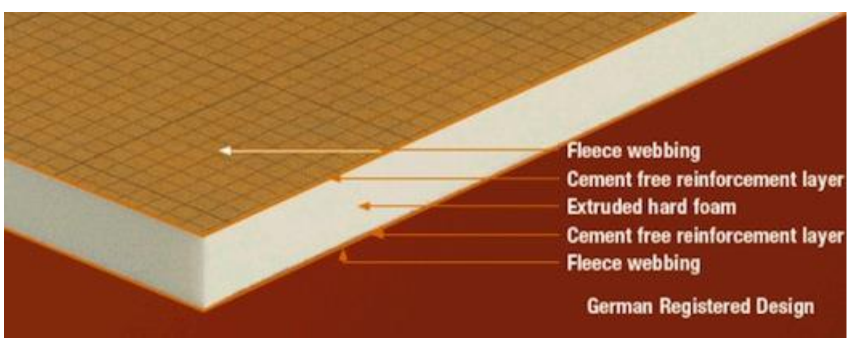
Conceptual Alternatives

Kerdi-Board Slicing

The first part of the process step is Kerdi-board slicing. The main idea here is to slice the 96”x48” Kerdi-Board into six equally sized pieces of dimensions 16”x48”. This is shown in the figure below:



For the slicing process, there were several key considerations that we had to take into account. These considerations include accuracy, speed and finish quality. But Styrofoam is a very difficult material to cut. It may melt when cut at high speeds.



After conducting research on the possible slicing equipment available, machine selection was reduced to the following:

- Hot Wire cutting machine
  Machine consists of a thin metal wire, often made of nichrome or stainless steel, heated via electrical resistance to approximately 200°C. As the wire is passed through the Styrofoam kerdiboard, the heat from the wire vaporizes the material just in advance from contact.
- Abrasive Wire cutting machine

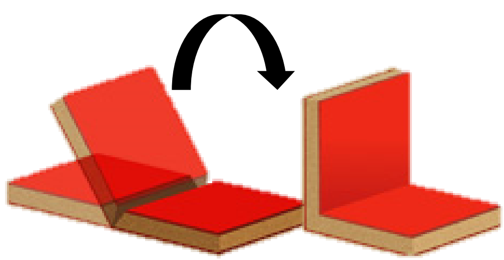
This machine uses abrasion to cut. The wire is typically roughened to be abrasive, or abrasive compounds are bonded to the cable. Abrasive wire cutting is often done with a Computer Numerical Control device that automatically cuts the pattern (or patterns) using data taken directly from a CAD/CAM file.

- Oscillating Blade cutting machine
  This machine essentially uses a metal saw blade that oscillates at very high frequencies to cut the foam.
- Vertical Knife cutting machine
  This machine uses a narrow width band knife blade, of width ≤ 10mm. The kerdiboard to be cut is supported on a flat table while it is cut.

Groove Routing:

In the groove-routing phase, 2 V-shaped grooves are carved through the cross-section of the Kerdi-board, and routed along the entire length of the piece. The V-grooves needed to be cut without damaging the waterproofing material at the bottom surface. We also required a good surface finish allowing for a 90 degree folding of the board when complete. Our cutting methods were constrained to those that would not overheat the material, since the Styrofoam would melt at very high temperatures.

Cross Section of Kerdiboard showing V-grooves



90 degree folding once V-grooves are cut

For the grooving tool to be used, the options were narrowed down to the following:

- 45^{o} tangential knife

  Pros:
  - High quality surface finish
  - Precise Cut

  Cons:
  - 2 passes per V-groove are required
  - High stresses on the board
  - Slow cut
  - Difficulty removing large scrap pieces automatically

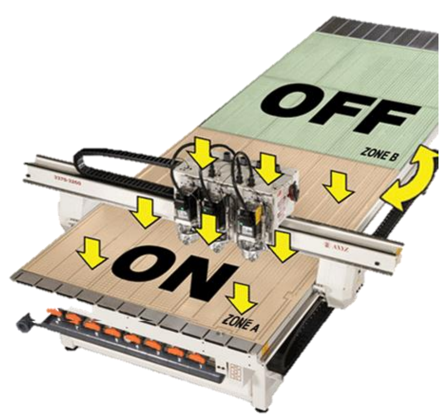
- V-bit router

  Pros:
  - Fast cut
  - Only need to be feed twice to cut a v-groove
  - Lower stresses on board
  - Easy automated chip removal

  Cons:
  - Slightly lower quality surface finish, but acceptable for high density material

We decided to use a CNC machine for the groove routing process in order to fully automate the process and give us an unparalleled level of versatility and programmability. The CNC machine would also provide us with integrated vacuum hold down, chip removal and tool change options.

We investigated using twin carriages on the same gantry to double our productivity by cutting



both grooves at the same time.

In addition, the prospect of employing a back-and-forth process was looked at (known as Pendulum Processing), whereby the machine bed is split into 2 virtual zones so that a sheet can be processed on one zone while the operator removes the parts from the other zone and a new sheet is loaded ready to be cut. Automatic switching of the vacuum hold-down and material locating pins are fully integrated for seamless, continuous production.

Adhesive Application:

Three ways to apply adhesive were examined: spray glue, hot melt glue and tape. As mentioned before, we have two alternate paths we considered for adhesive application: Gluing and taping. So we chose one option for gluing and one for taping while keeping the considerations of total price, overall speed, effectiveness and – last but not least—safety in mind. These adhesives will be applied in the grooves cut in the previous operation along its whole length so that it could be folded and stay in a U-shape. The folding will be done in the following folding process if glued and will be done by the customer during installation if taped.

Gluing:

For the gluing process, pressure activated hot melt glue and spray glue were considered. Although solvent-based spray glue has its advantages, pressure activated hot melt requires less maintenance, volatile organic compounds are reduced and the glue is less expensive. In addition, a curing process is unnecessary, it has a longer open time and it can be used at a relatively low temperature (around 125C) so that the product will remain intact.

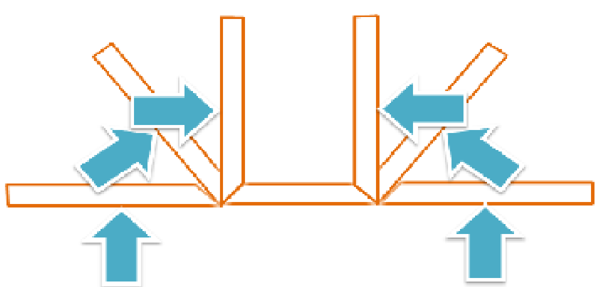
Taping:

For the alternate taping process, we looked at various options for tape applicators and industrial tape that would be able to apply a narrow width of about a quarter inch in the grooves. Another criteria was that the applicator had to access the grooves and apply the tape at a 45-degree angle.

Folding

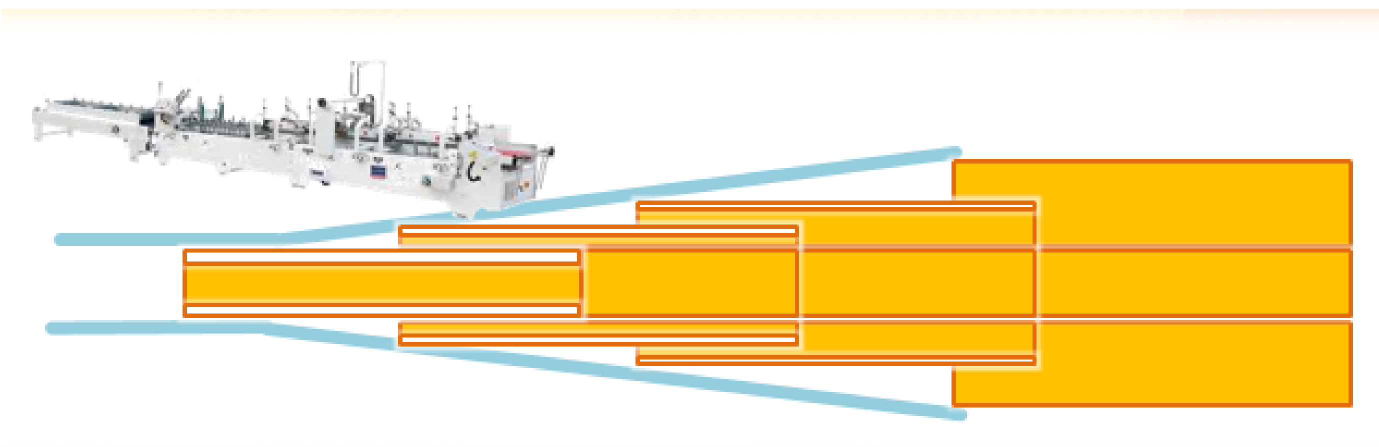
For the folding stage, various options were considered to fold up the sides of the kerdiboard in order to cure the adhesive. It is worth noting that the folding process would only be required in our manufacturing line if we opt for gluing (and shipping folded) rather than taping (and shipping flat). The options we came up with are as follows:

- Mechanical Arm system
  Essentially, this is a mechanical device that applies a force on the sides of the board to lift them up by 90 degrees.



- Drop Down System
  This is a machine that would allow the board to drop into a narrower section pathway and force the two sides to folded up, as shown below.

- Gradual Glide or Tunnel System
  In this method, the machine forces the kerdiboard into a tapered ''tunnel'' that gradually becomes narrower and pushes the sides of the board upwards, thereby folding them.



Packaging

For packaging, we required a single machine that would be able to accommodate all our needs. Ideally, the machine would include:

- Case Erector to construct the cartons
- Case Packer to enrobe the products in the carton
- Case Sealer to seal the carton effectively
- Case Palletizer to stack the cartons in pallets and ready for shipping

We researched several machines that would be able to accomplish these functions in our manufacturing line. All the machines had similar specifications. They cost approximately USD 50,000 and had capacities of around 10 cartons per minute. We picked one equipment as a model for our project that had the scope for customization to handle large carton sizes, since the carton dimensions in our project are rather large (48” in length). This was the Shanghai Zinglu 4-in-1 Complete Packaging System, shown in the figure below.

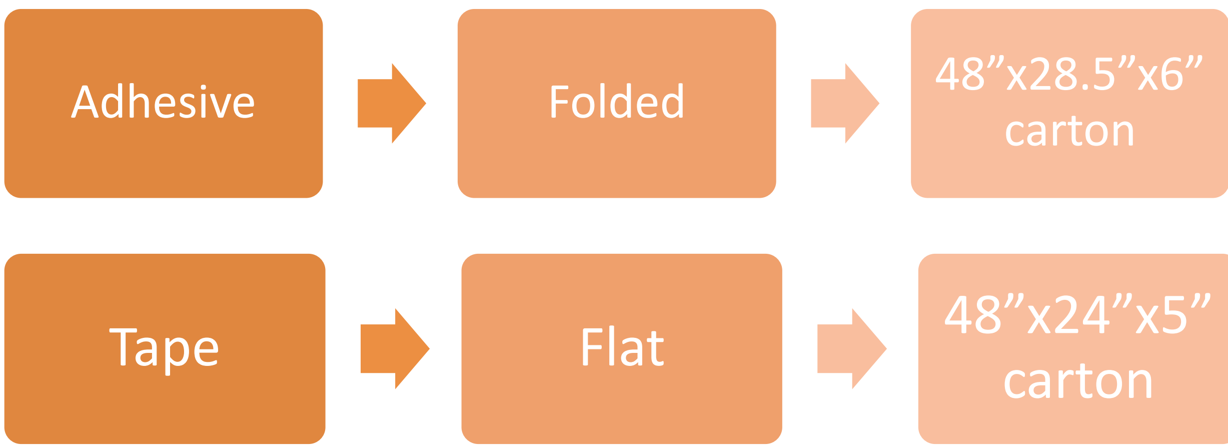
Regarding the carton size, we are presented with two options, depending on whether we decide to ship the kerdiboard folded, or flat (note that the product is packaged together with the Schluter Shower base):

- Folded
  - *Box dimension: 48"x 28.5" x 6"*

- Flat
  - *Box dimension: 48"X 24" x 5"*

Therefore, the carton size depends directly on whether we are selling our final product in a folded or flat state. The packaging machine we selected is capable of producing both sizes of cartons.

Shipping

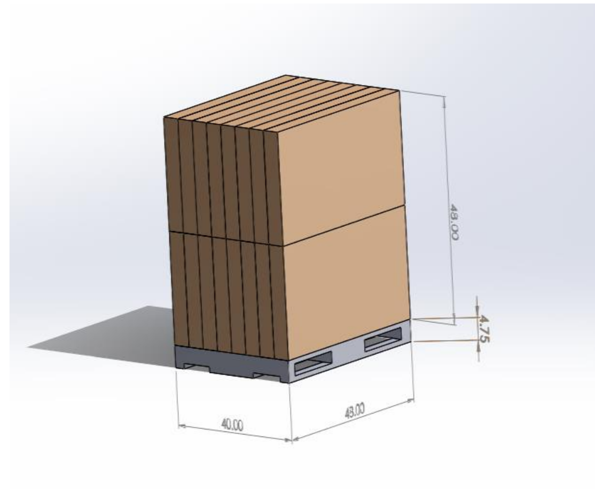


As discussed already, the shipping aspect of our process depends on whether we are selling our final product folded or flat. If we apply adhesives, we will sell a folded product in the market and have a carton size of dimensions 48"x28.5"x6". On the other hand, if we apply tape, we will sell the final product in a flat state (with the customers responsible for removing the tape and folding the shower curb themselves) giving us carton dimensions of 48"x24"x5". Both options are feasible provided investment is made on a proper industrial packaging machine such as the Zinglu 4-in-1 Complete Packaging System presented in the 'Packaging' section.

Regarding the costs associated with shipping, we calculated the total expenses on a per-pallet basis. A standard pallet size is 48” x 40” x 4.75”. Based on this, we found:

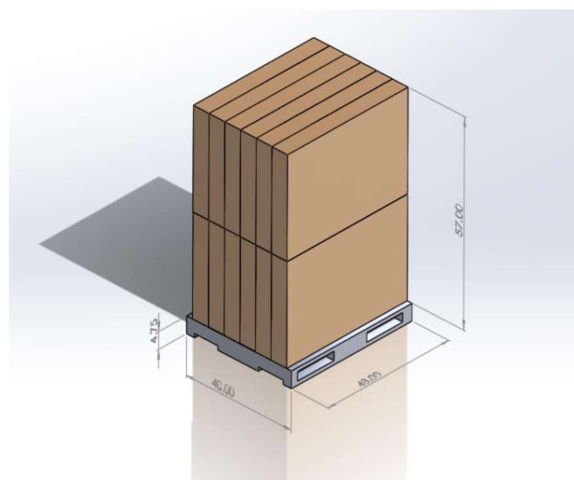
Flat

- Each carton has dimensions 48”x24”x5”
- 8 boxes on one tier of pallet (2 tiers/pallet)
- Total of 16 boxes per pallet
- Cost of shipping each carton = $6.25



Folded

- Each carton has dimensions 48”x28.5”x6”
- 6 boxes on one tier of pallet (2 tiers/pallet)
- Total of 12 boxes in each pallet
- Cost of shipping each carton = $8.33



Concept Evaluation Process

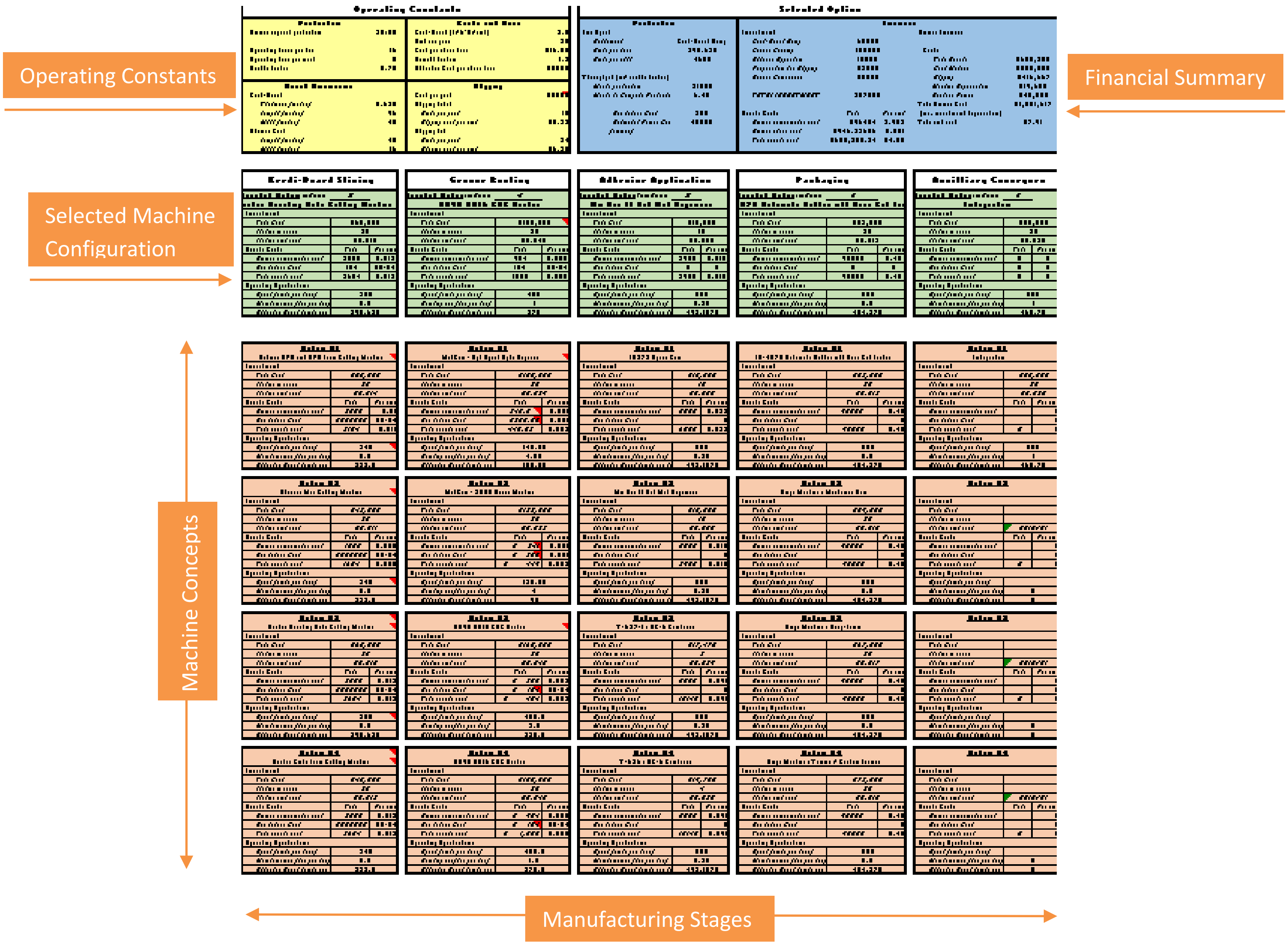
The concept generation process allowed us to generate four different concepts for each of the four stages of the manufacturing line. This is a grand total of *16 machine concepts* that need to be analysed and evaluated thoroughly. To accomplish this goal, handy tools and methodologies were designed. The evaluation process was divided into two sections: quantitative analysis and qualitative analysis.

	Quantitative Analysis	***Qualitative Analysis***
Description	Evaluation of the data related to the costs and specifications of the machine concept	Evaluation of the needs of the manufacturing process that are met by the machine concept
Type of data	Costs	Satisfaction of the needs
Method	Financial Cost Analysis	Weighted Decision Matrix
Goal	Obtain a total annual cost for a specific assembly line configuration	Obtain a total score of satisfaction of the needs for a specific assembly line configuration

Quantitative Analysis

In this section, costs and specifications related to each and every concept generated were collected and evaluated rigorously in order to perform a financial cost analysis of the manufacturing plant. Below is an overview of the master excel sheet that enabled this analysis.

Cost Evaluation Table



Pink Section

Option #1		
Hotwire EPS and XPS Foam Cutting Machine		
Investment		
Total Cost	*$55,000*	
Lifetime in years	*20*	
Lifetime unit cost	*$0.014*	
Variable Costs	*Total*	*Per unit*
Annual consumables cost	*2000*	0.01
Daily Labour Cost	*$104.00*	0.00052
Total variable cost	*2104*	0.01052
Operating Specifications		
Speed (units per hour)	240	
Maintenance (hrs per day)	0.5	
Effective Speed (units per hr)	232.5	

Each column in the pink section represents a different stage in the manufacturing process: *board slicing, groove cutting, adhesive application, shipping preparation*.

Each row represents a different machine concept (4 concepts per stages)

On the right an enlarged picture of the table in the first row and first column is shown.

Each pink table contains information related *to investment, variable costs and operating specifications* for a specific machine concept, in this case a hotwire foam cutting machine.

Green Section

This section represents a specific combination of machine concepts in order to evaluate the finance of an assembly line of your choice. This section is, therefore, modular, by simply interring the concept number of your choice in the *Selected Option* line (circled in red below), all the data specific to this concept will be imported into the calculations.

Kerdi-Board Slicing		
Selected Option *Number:* 3		
Vertical Oscillating Blade Cutting Machine		
Investment		
Total Cost	$60,000	
Lifetime in years	20	
Lifetime unit cost	$0.015	
Variable Costs	*Total*	*Per unit*
Annual consumables cost	2500	0.0125
Daily Labour Cost	104	0.00052
Total variable cost	2604	0.01302
Operating Specifications		
Speed (units per hour)	300	
Maintenance (hrs per day)	0.5	
Effective Speed (units per hr	290.625	

Groove Routing		
Selected Option *Number:* 4		
AXYZ 5016 CNC Router		
Investment		
Total Cost	$180,000	
Lifetime in years	20	
Lifetime unit cost	$0.045	
Variable Costs	*Total*	*Per unit*
Annual consumables cost	954	0.00477
Daily Labour Cost	104	0.00052
Total variable cost	1058	0.00529
Operating Specifications		
Speed (units per hour)	400	
Handling loss (hrs per day)	1	
Effective Speed (units per hr	375	

Adhesive Application		
Selected Option *Number:* 4		
T-626 + UC-6 Controller		
Investment		
Total Cost	$19,750	
Lifetime in years	4	
Lifetime unit cost	$0.025	
Variable Costs	*Total*	*Per unit*
Annual consumables cost	18148	0.09074
Daily Labour Cost	0	0
Total variable cost	18148	0.09074
Operating Specifications		
Speed (units per hour)	500	
Maintenance (hrs per day)	0.25	
Effective Speed (units per hr)	492.1875	

Packaging		
Selected Option *Number:* 1		
LX-407S Automatic Slotter with Rear Kick Feeder		
Investment		
Total Cost	$52,000	
Lifetime in years	20	
Lifetime unit cost	$0.013	
Variable Costs	*Total*	*Per unit*
Annual consumables cost	90000	0.45
Daily Labour Cost	0	0
Total variable cost	90000	0.45
Operating Specifications		
Speed (units per hour)	500	
Maintenance (hrs per day)	0.5	
Effective Speed (units per hr)	484.375	

Yellow Section

This section contains all the operating constants required to perform the financial calculations. These constants are separated into four groups: *production, board dimensions, costs and sales and shipping*

Operating Constants			
Production		**Costs and Sales**	
Annual required production	200000	Kerdi-Board (1/6*$/unit)	2.5
Operating hours per day	16	Cost per labour hour	$16.00
Operating days per week	5	Benefit burden	1.3
Reliability factor	0.75	Effective Cost per labour hour	$20.80
Board Dimensions		**Shipping**	
Kerdi-Board		Cost per pallet	$150.00
Thickness (inches)	0.625	Shipping folded	
Length (inches)	96	*Units per pallet*	18
Width (inches)	48	*Shipping cost per unit*	$8.33
Shower Curb		Shipping flat	
Length (inches)	48	*Units per pallet*	24
Width (inches)	16	*Shipping cost per unit*	$6.25

Blue Section

This section is the most important part of this excel sheet. It summarises all the results of excel calculations. It tells us which stage of the manufacturing line is the bottleneck and what is the weekly production. It also breaks down the *total investment, variable costs and other costs* associated with the production. The number that is of most interest for the purpose of this evaluation is the *Total Annual Cost*. It gives us the overarching annual cost of a specific configuration of the manufacturing line, which is exactly the goal of the Quantitative Analysis. One simply needs to change the concept number in the green section in order to obtain an evaluation of the total annual cost of a completely different assembly configuration.

Selected Option						
Production		**Finances**				
Line Speed		Investment			Annual Finances	
Bottleneck	Kerdi-Board Slicing	*Kerdi-Board Slicing*	60000			
Units per hour	290.625	*Groove Carving*	180000		Costs	
Units per shift	4650	*Adhesive Application*	15000		*Total Variable*	$605,350
		Preparation for Shipping	52000		*Kerdi Material*	$500,000
Throughput (w/ reliability factor)		*Auxilliary Conveyors*	80000		*Shipping*	$416,667
Weekly production	31000				*Machine Depreciation*	$19,600
Weeks to Complete Production	6.45	*TOTAL INVESTMENT*	387000		*Electrical Power*	$40,000
					Total Annual Cost	$1,581,617
Daily Labour Cost	208	Variable Costs	*Total*	*Per unit*	(incl. investment depreciation)	
Estimated Power Cost (annual)	40000	*Annual consumables cost*	596404	2.98202	Total unit cost	$7.91
		Annual labour cost	8946.236559	0.00104		
		Total variable cost	$605,350.24	$4.55		

Qualitative Analysis

Upon completion of the cost analysis, we came to realize that although our evaluation included all the data we could find, we felt that the analysis was incomplete. A dimension of the concepts was not taken into account. This dimension could not be quantified with numbers, but it represented the merit of the machine. Therefore a method was designed to evaluate how well each machine concepts *satisfied the needs* of the manufacturing process.

Weighted Decision Matrix

Decision Factors Groove Cutting Stage		Concept 1	Concept 2	Concept 3	Concept 4
Criteria	Wt.	1	2	3	4
Reliability	3.0	4	4	5	5
Level of Automation	2.5	2	2	3	3
Overall Quality	2.0	5	5	4	4
Waste Management	1.5	3	3	5	5
Feed Speed	2.0	2	1	2	5
Weighted Scores		35.5	33.5	42.0	**48.0**

A weighted decision matrix method was chosen in order to evaluate the qualitative criteria of each machine. The criteria were selected based on how well they satisfied the needs and a corresponding weight was assigned to each one of them. They are *reliability, level of automation, overall quality, waste management and an extra criteria* specific to the manufacturing stage under investigation.

Looking at one stage of the manufacturing process at the time, the four concepts generated were given a score for each criteria on a scale from 1-5. Each number in the grading scale was given a specific definition. The definitions can be found in the appendix.

The decision matrix will highlight automatically the concept with the highest satisfaction score. As you can see in the table above at the groove cutting stage *Concept 4* provides the highest satisfaction of the needs. This process is then repeated for each stage of the manufacturing process.

Decision Factors	Cutting	Grooving	Adhesive	Folding	Total Weighted Score
Best Satisfaction of Needs	3	4	2	1	
Score	42.5	48.0	45.5	44.5	180.5

In the table on the left, the total weighted score of the machine configuration that best satisfied the needs is calculated. This total score gives us a numerical value on how well a specific machine configuration satisfies the needs of the manufacturing line. It is now possible to easily compare the merit of a manufacturing line with any combination we want.

To summarise the concept evaluation, two different tools were created to perform an evaluation of the manufacturing line concepts.

The quantitative analysis allows us to calculate a total annual cost that comprises every cost incurred by the manufacturing plant for a specific machine configuration.

The qualitative analysis allows us to give a numerical score that matches the level of satisfaction for any machine configuration.

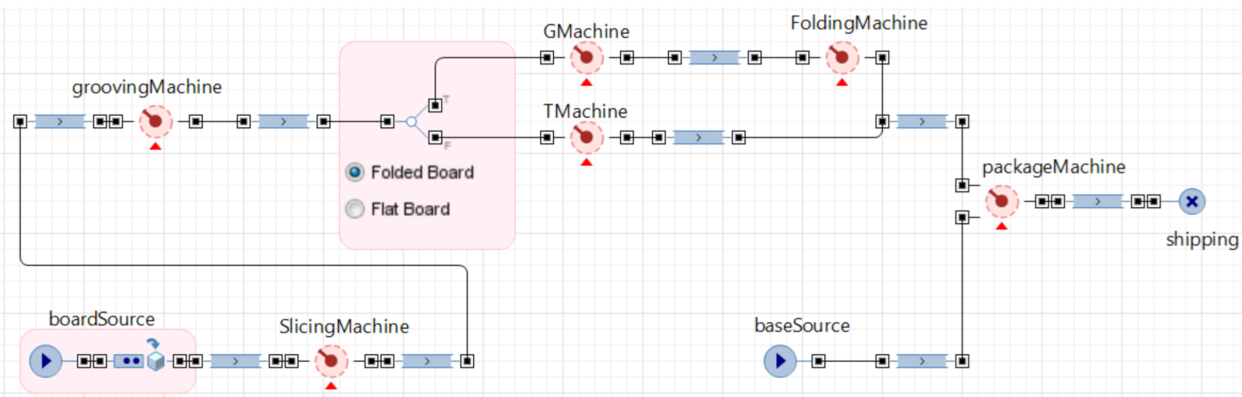
When these two tools are combined, we end up with a total of **128 permutations** of possible combinations. In the next section, we will show how we made use of the optimisation tool in *Excel* to sort out the permutations with the highest *Value*.

Manufacturing Line Simulation

A simulation of the entire manufacturing line was created. It enables us to visualize and analyse how well each stage of the manufacturing fits together when connected with conveyers. The diagram below is the manufacturing line control panel. Each red node is a machine in the line.

From the control panel, we can control the nature of the input and output at every red node, as well as, the speed at which the machine can perform its task. It is therefore possible to monitor the unit production rate of the entire line and identify possible issues, such as the line bottleneck.

Manufacturing Line Control Panel

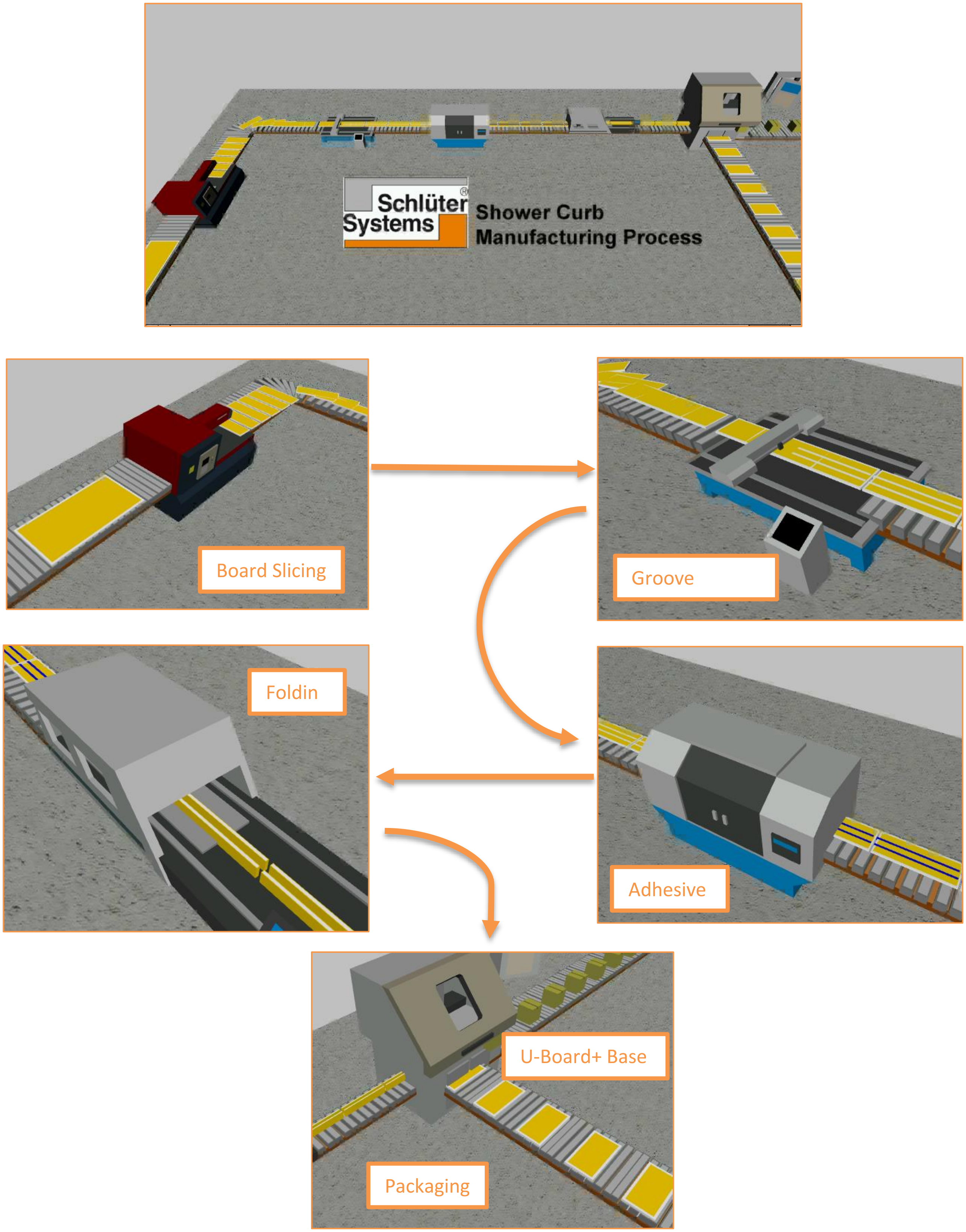


Depending on which shipping method we want to investigate, the manufacturing line can easily switched from the two possible packaging preparation. In the control panel select "Folded Board" to modify the line so that glue is applied in the grooves and the Kerdi board is pre-folded before entering the packaging machine. The "Flat Board" can also be selected so that only doubled sided tape is applied in the grooves and the board is kept flat before entering the packaging machine.

The simulation also allows to simulate how the base shower base will be combined with the *Kerdi Board U* to be packaged together. This enables us to identify at what speeds the shower base needs to be feed inside the machine.

Below screenshots of the running simulation illustrate how the different manufacturing stages come together.

Overview of the Manufacturing Line Simulation


Schlüter Systems
Shower Curb
Manufacturing Process
Board Slicing
Groove
Foldin
Adhesive
U-Board+ Base
Packaging

Proposals

Introduction

Multiple concepts were generated and evaluated for each stage in the manufacturing process (Figure 1). As a result, four options are available for slicing and groove cutting respectively. At the stage of adhesive application, two taping machines are available for flat shower curb and two gluing machines are available for folded shower curb. The manufacturing of folded shower curb needs an extra step, folding, where three options are available. Then, a complete packaging system is found for the packaging of both flat and folded shower curb.

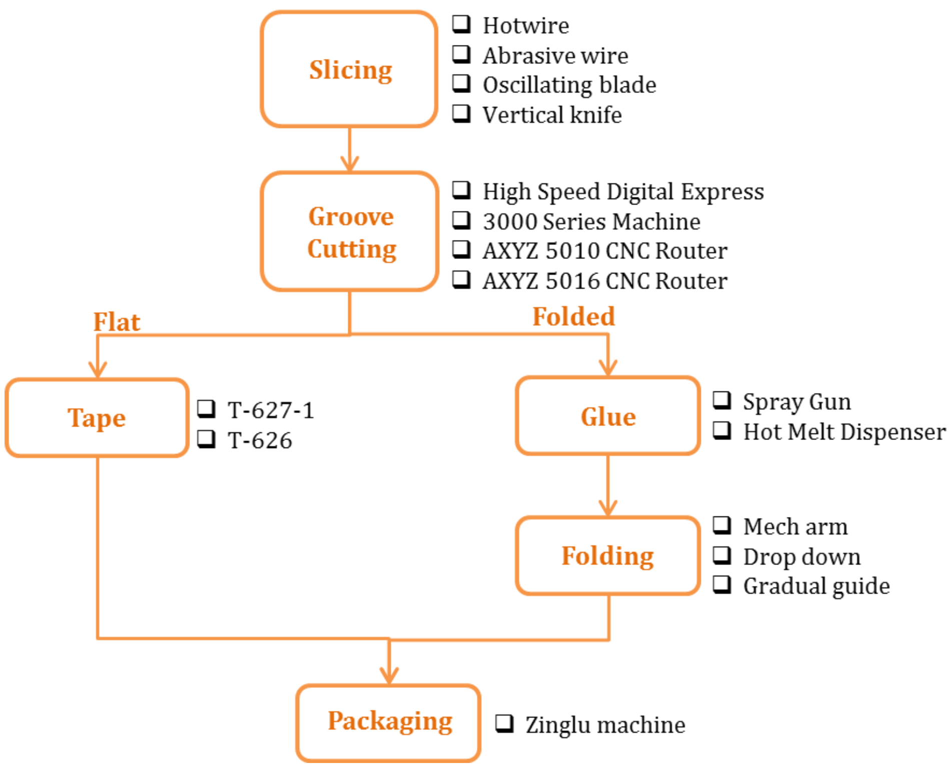


Figure 1 Options for manufacturing stages

Combining different machine in each stage, one can get various production lines. The manufacturing of flat shower curb has 32 combinations ($4 \times 4 \times 2 \times 1 = 32$) and the manufacturing of folded shower curb has 96 combinations ($4 \times 4 \times 2 \times 3 \times 1 = 96$). A good solution should propose a complete production line that has the best value, reaches the minimum satisfaction and maintains reasonable cost. Section 0 introduces the method of selecting the best solutions from all the 128 combinations; four solutions are proposed in section 0 and compared in section 0.

Approach to Solution Selection

In order to propose solutions that have good value as well as meet the minimum satisfaction, we calculated the value of each possible combination and determined the minimum satisfaction .

Calculation of Value

Since value is defined as positively related to the ratio of the satisfaction of needs and cost, the following formula (Equation 1) was used to calculate the value of different production lines.

$$\mathrm{Value_{line}} = \frac{\mathrm{Satisfaction_{line}}}{\mathrm{Cost_{line}}} \qquad \text{Equation 1}$$

The satisfaction of each machine was quantified in concept evaluation. Thus, the satisfaction of a production line ($\mathrm{Satisfaction_{line}}$) can be calculated as the sum of the satisfaction of each machine ($\mathrm{Satisfaction_{machine}}$) in the line (Equation 2).

$$\mathrm{Satisfaction_{line}} = \sum \mathrm{Satisfaction_{machine}} \qquad \text{Equation 2}$$

Annual manufacturing cost of a production line was used as the cost in value calculation. It includes the sum of annual cost of each machine ($\mathrm{Cost_{machine}}$), the annual consumption of Kerdi boards (Material), annual cost on electric power ($\mathrm{Electric}$) and annual shipping cost (Shipping) as shown in Equation 3. Equation 4 gives the annual cost of each machine ($\mathrm{Cost_{machine}}$), which includes annual depreciation of the machine ($\mathrm{Depreciation = \ Investment/lifetime}$), annual cost on consumables such as glue in adhesive application, corrugated paper in packaging, etc. (Consumable) and annual labor cost on the machine (Labor).

$$\mathrm{Cost_{line}} = \sum \mathrm{Cost_{machine}} + \mathrm{Material} + \mathrm{Electric} + \mathrm{Shipping} \qquad \text{Equation 3}$$

$$\mathrm{Cost_{machine}} = \ \mathrm{Depreciation} + \mathrm{Consumable} + \mathrm{Labor} \qquad \text{Equation 4}$$

Following this method, we obtained the satisfaction, cost and value of all possible production lines.

Minimum Satisfaction

Minimum satisfaction was set in order to prevent selecting inferior solutions whose poor satisfaction is compromised by low cost. Since the satisfaction was evaluated based on a scale of 1 to 5, we used 3.5 as acceptable value for each criterion, which gave 143.5 in total. Thus, solutions with satisfaction lower than 143.5 were excluded.

Proposed Solutions

Solutions of the highest value, the highest satisfaction or the lowest cost for manufacturing either flat or folded shower curbs were of interest. The result of value calculation showed that the solutions with the highest value happened to have the highest satisfaction. Thus, four solutions – best value flat, best cost flat, best value folded and best cost folded – were proposed. The machines in each stage with their corresponding satisfaction (S) and cost (C) are listed in Table 1.

Table 1. Proposed solutions

	Best value flat		Best cost flat		Best value folded		Best cost folded	
Slicing	Oscillating blade	S=42.5 C=5.6	Abrasive wire	S=33.5 C=3.7	Oscillating Blade	S=42.5 C=5.6	Abrasive wire	S=33.5 C=3.7
Groove Cutting	5016 CNC router	S=48 C=9.8	3000 series	S=33.5 C=7.1	5016 CNC Router	S=48 C=9.8	3000 series	S=33.5 C=7.1
Adhesive	T-626 tape	S=36.5 C=23.1	T-626 tape	S=36.5 C=23.1	Hot melt	S=45.5 C=3.95	Hot melt	S=45.5 C=3.95
Folding & Packaging	Zinglu machine	S=45 C=405	Zinglu machine	S=45 C=405	Gradual guide +Zinglu machine	S=38 C=510	Mech arm + Zinglu machine	S=33.5 C=510
Total satisfaction	**172**		**148.5**		**174**		**146**	
Total cost	**9.88**		**9.83**		**10.74**		**10.68**	
Value	17.41		15.10		16.21		13.66	

Note 1: S is machine satisfaction; C is machine annual cost calculated by Equation 4 (unit: \$K).
Note 2: Total cost is annual manufacturing cost calculated by Equation 3 (unit: $\$10^5$).

Comparison of Proposals

Merit/Cost Comparison

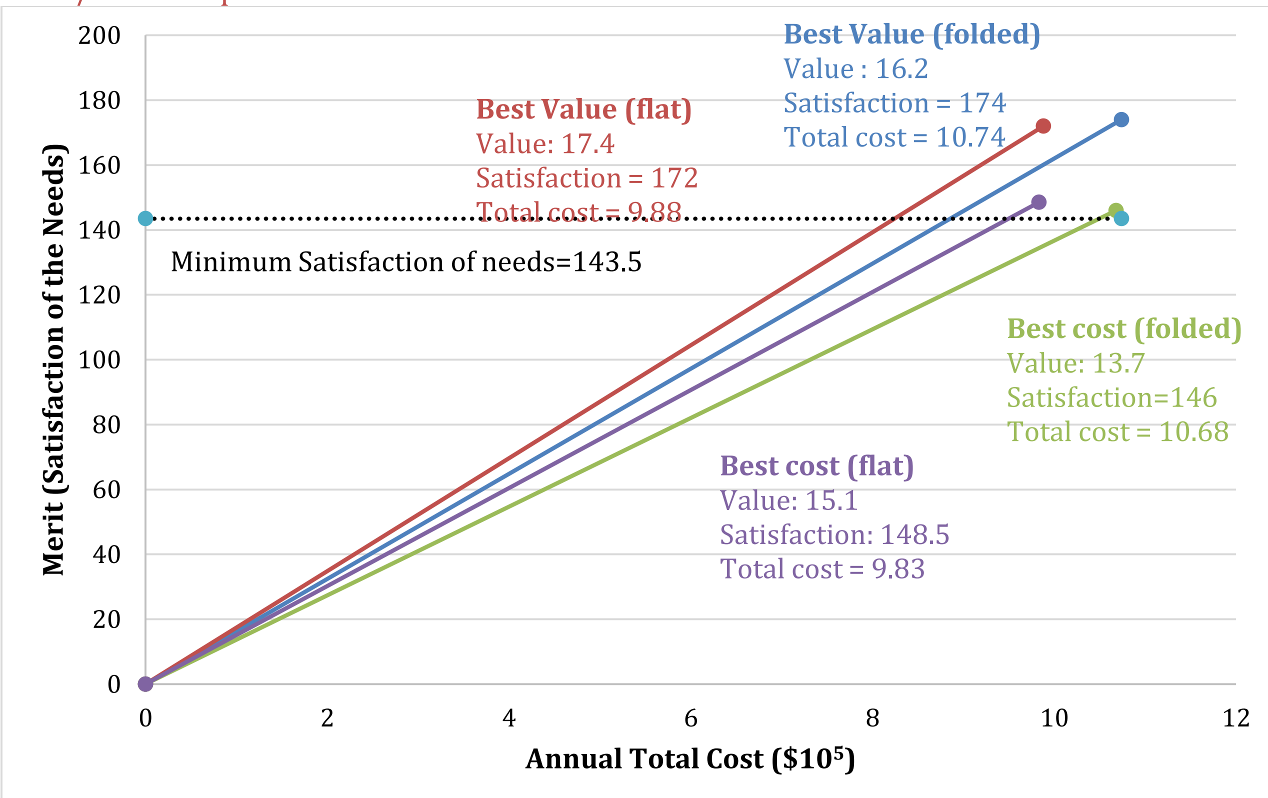


Figure 2 Merit/Cost comparison of proposed solutions

The value of proposed solutions was compared through merit/cost comparison chart (**Error! Reference source not found.**). In the chart, the horizontal axis indicates the total annual cost and the vertical axis indicates the satisfaction of needs. Different proposals were represented as lines in different colors. Greater slope means higher value.

It can be seen that, compared with solutions with the best value, solutions with best cost have merit reduced more than 13% with less than 0.6% savings in cost. Besides, there was no constraint on cost according to the client. Therefore, solutions with best cost were eliminated.

The solution with best value flat has the greatest value but the solution with best value folded has higher satisfaction and reasonable cost. In order to further compare the two solutions, financial analysis was conducted in the next section.

Financial Analysis

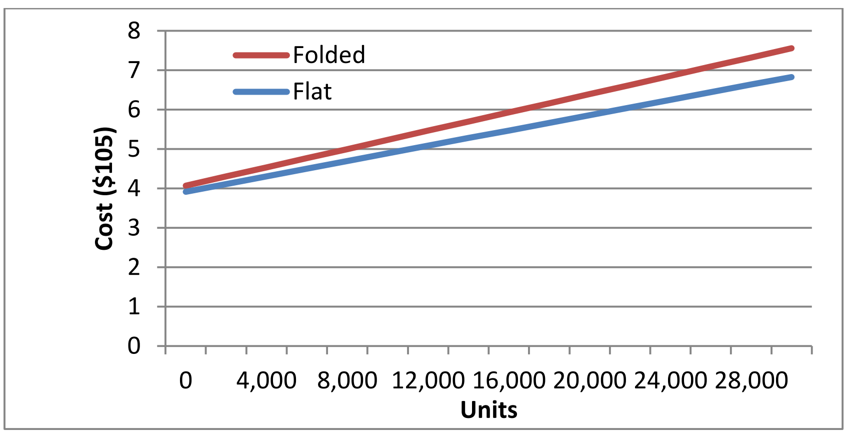
The sale price of the new shower curb is not set as it is new to the market; so, we only analyzed the cost and made assumptions when necessary. Table 2 lists the cost information of solutions with the best value in both flat and folded scenarios.

Table 2 Cost information of solutions

	Best value flat	Best value folded
Variable cost ($)	**9.70**	**11.62**
Consumable & labor	0.56	0.48
Material	2.5	2.5
Power	0.2	0.2
Shipping	6.25	8.33
Fixed cost ($)	**391750**	**407000**

Break Even Point (BEP)

Figure 3 shows how the total cost increasing with more units produced. Although the sale price was not available, it is apparent from the figure that, to reach the BEP, the flat solution always requires fewer units to be produced than the folded solution does.



Ordinate labels
Cost ($105) & units 0 ... 8
meaning unclesr

Figure 3 Total cost increasing with more units produced

Payback Period

In order to estimate the financial risk, we used Equation 5 to calculate the payback period.

$$\text{Payback period} = \frac{\text{Fixed cost}}{(\text{sale price} - \text{variable cost}) \cdot \text{annual production}} \qquad \text{Equation 5}$$

Assuming 200,000 units of annual production and using cost information from Table 2, we were able to study how the payback period changes with sale price in in each scenario (Figure 4).

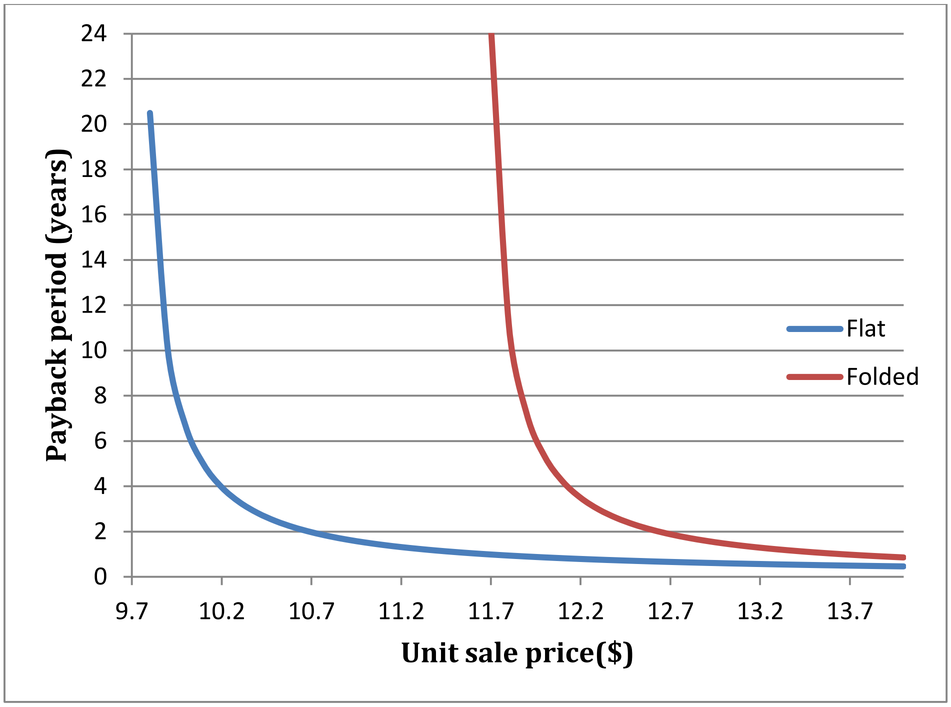


Figure 4 Payback period varying with sale price in flat and folded scenarios

Interesting; seems that for a 2yr PBP the folded curb should be "worth" $2 more than a flat one.

From the figure above, we can have the following conclusions:

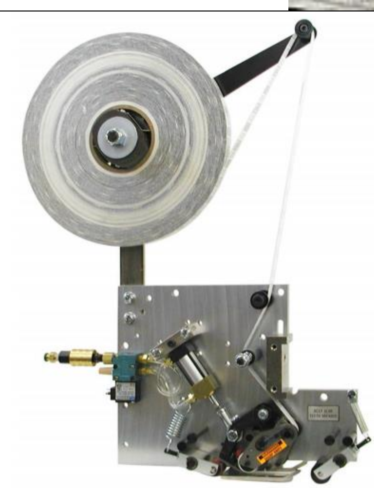
(1) with a fixed sale price, the flat solution pays back faster than the folded solution; and
(2) with a certain goal of payback period, the flat solution allows lower unit sale price, which probably attract more customers.

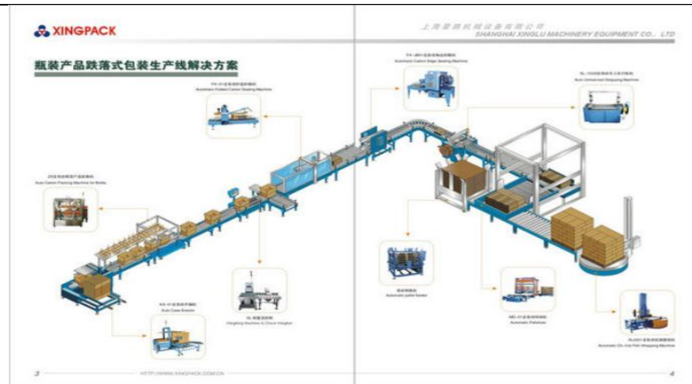
Therefore, the flat solution is superior to the folded solution from the perspective of BEP and payback period.

Proposed Solution – Ship the Product Flat

Ultimately, we found that the most value comes from shipping the product flat. The optimal manufacturing line that creates the shower curb is shown in Figure ##. A vertical knife CNC was selected for Kerdi-Board Slicing since for its advantageous speed and surface finish. Furthermore, there are minimal concerns with heat generation, whereas this is a major concern for a hot wire or oscillating blade. Given the nature of the material and the cutting mechanics involved, we found that this is the optimal solution.

Figure ## - Proposed Solution (Flat)

Process Step	**Selected Option**	
Kerdi-Board Slicing	Vertical Knife CNC	
Groove Routing	Double –carriage, V-bit Router CNC with Pendulum Process	 
Adhesive Application	T-626 Double-Sided Taper	

Packaging	Zinglu 4-in-1	

For Groove Routing, we found that the double-carriage, V-bit router CNC machine with the pendulum process gives the most value. Although it is the most expensive option, its two tool carriages allow parallel processing, therefore doubling the effective output speed of the machine. Furthermore, the groove router only requires one pass in comparison to the 45 degree knife which requires two passes per groove. It features a very efficient waste ship removal system so as to minimize labour requirements and mitigate jam-ups. Lastly, it has a very large workspace which permits the pendulum process to continuously output products. Although the surface finish is inferior to that of the knife, it is sufficient for this application since we are working with high-density foam.

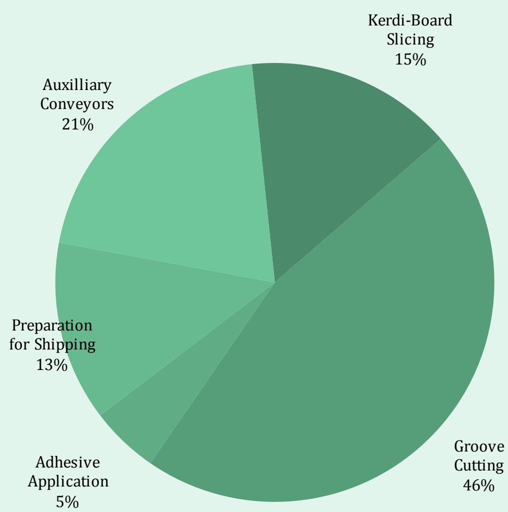
We recommend that Adhesive Application is carried out by a double-sided taper, acting at a 45 degree angle to the plane of the Kerdi-Board. The T-626 offers a flexible, faster, and more robust than the other machines considered. It has the versatility to act at varying angles, allowing it to be used in multiple applications.

To package the product with the base and its accessories we propose to use the Zinglu 4-in-1 Packing system. It provides the capacity to handle our size requirements, significant run speed to avoid bottlenecking, and the reliability to avoid jam ups. Also, its complete automation and integration eliminates the need for additional labour.

The pie charts below illustrate the distribution of investments and annual cost of the Best Value (flat) proposal.

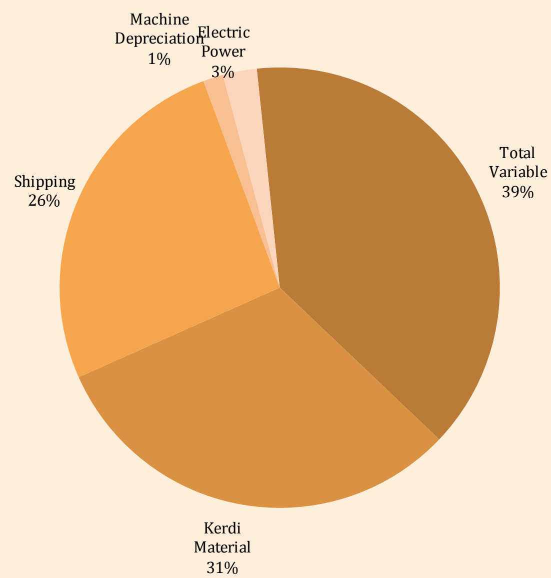
Investment Distribution

Assembly Line	Investment Cost
Kerdi-Board Slicing	$60,000
Groove Cutting	$180,000
Adhesive Application	$19,750
Preparation for Shipping	$52,000
Auxilliary Conveyors	$80,000
Total Expenses	**$391,750**



Annual Cost Distribution

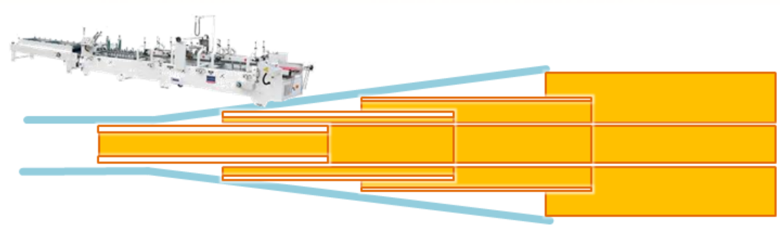
CATEGORY	Annual Cost
Total Variable	$620,548
Kerdi Material	$500,000
Shipping	$416,667
Machine Depreciation	$23,538
Electric Power	$40,000
Total Expenses	**$1,600,753**



Alternative Solution – Ship the Product Folded

Shipping the product flat does provide the most value; however, if further market research shows that there it is in Schluter's best interest to ship the product folded – i.e. there is more demand for a folded product, there are legal risks with shipping flat, etc. – then there is also value in shipping the product folded. This manufacturing line features the same Kerdi-Board Slicing, Groove Cutting, and Packaging machines, but with different machines for Adhesive Application. The optimal manufacturing line to accomplish this is shown in Figure ##.

Figure ## - Selected Gluing and Folding Machines for Folded Product

Process Step	Selected Option	
Adhesive Application	Miniblue II Hot Melt Dispensing	
Folding	Tapered Tunnel	

The Miniblue II Hot Melt Dispensing Gun was chosen as the best adhesive applier for this application. It requires less maintenance and uses less expensive glue than the other options. Furthermore, it cures faster than other options so using this machine avoids bottlenecking or the need for an accumulator.

To fold the shower curb, we found that the tapered tunnel offers the best solution. Its simplicity, low cost, high automation and high reliability make it the optimal solution.

Conclusion

Through following the structure of value engineering analysis we were able to develop and evaluate over 100 different, workable manufacturing lines. From information gathering, we were able to determine the functions that our design needed and the constraints by which it was limited. After that we used brainstorming techniques to generate concepts for each of the functions. From there, we developed systems to evaluate both the quantitative and qualitative aspects of each of the concepts. Then, using an optimization tool and modelling software we were able to determine the optimal solutions according the Value Engineering criteria.

We selected the combinations of equipment on the basis of maximum total value and minimum total cost. It was found that the best value comes from shipping the product flat. However, if Schluter decided to sell the product folded, there was value in this as well. Therefore, the Best Value and Best Cost combinations were provided for both a folded product and flat product.

Appendix

Weighted Decision Matrix – criteria and scale definition

Criteria	Definition	Scale
Reliability	Reliability of machine and components, potential downtime, ease of repair and component purchase. Standard machine setup with tested equipment will be much more reliable than highly costumized machine with uncommon setup.	1 = reliability issues, 2 = poor reliability, 3 = average reliability, 4 = good reliability, 5 = excelent reliability
Level of Automation	Automation of the process, waste removal, and level of integration into an automated line.	1 = unautomated, 2 = basic automation full time worker required, 3 = automated will minimal labor, 4 = fully automated process, but custumization needed for line integration, 5 = fully automated of process & full line integration
Overall Quality	Overal quality of product, surface finish and maintenance of functionalty	1 = unfunctinal result, 2 = poor finish, 3 = ok finish & functional 4 = good finish, 5 = excelent finish
Waste Management	Minimization of waste and removing method	1 = waste not removed, 2 = waste removed but not minimize, 3 = waste minimized and removed by worker , 4= waste fully minimized & removed partially automatically and with worker, 5 = waste fully minimized & automatically removed
Cutting Speed		

Weighted Decision Matrix – Cutting Stage

Decision Factors Cutting Stage		Concept 1	Concept 2	Concept 3	Concept 4
Criteria	Wt.	1	2	3	4
Reliability	3.0	2	3	4	4
Level of Automation	2.5	4	4	4	4
Overall Quality	2.0	2	2	4	4
Waste Management	1.5	4	3	3	3
Cutting Speed	2.0	3	3	4	3
Weighted Scores		32.0	33.5	**42.5**	40.5

Weighted Decision Matrix – Groove Cutting Stage

Decision Factors Groove Cutting Stage		Concept 1	Concept 2	Concept 3	Concept 4
Criteria	Wt.	1	2	3	4
Reliability	3.0	4	4	5	5
Level of Automation	2.5	2	2	3	3
Overall Quality	2.0	5	5	4	4
Waste Management	1.5	3	3	5	5
Feed Speed	2.0	2	1	2	5
Weighted Scores		35.5	33.5	42.0	**48.0**

Weighted Decision Matrix – Adhesive Stage

Decision Factors Adhesive Stage		Concept 1	Concept 2	Concept 3	Concept 4
Criteria	Wt.	1	2	3	4
Reliability	3.0	4	5	4	5
Level of Automation	2.5	5	5	3	3
Overall Quality	2.0	5	4	4	5
Waste Management	1.5	0	0	0	0
Lifespan	2.0	5	5	2	2
Weighted Scores		44.5	**45.5**	31.5	36.5

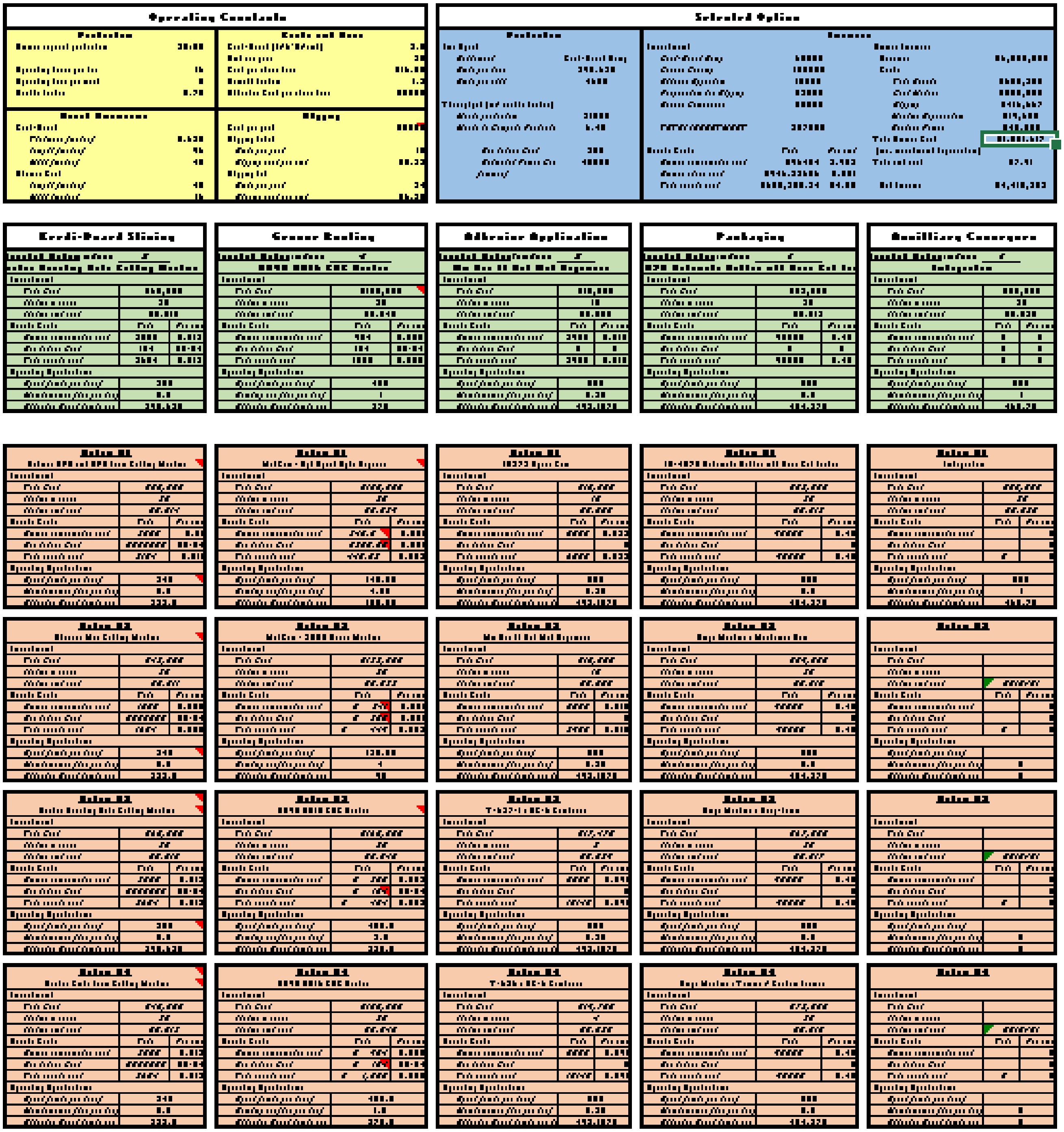
Weighted Decision Matrix – Folding Stage

Decision Factors Folding Stage		Concept 1	Concept 2	Concept 3	Concept 4
Criteria	Wt.	1	2	3	4
Reliability	3.0	5	4	3	4
Level of Automation	2.5	4	3	3	4
Overall Quality	2.0	5	4	4	4
Waste Management	1.5	0	0	0	0
Speed	2.0	5	3	2	4
Weighted Scores		**45.0**	33.5	28.5	38.0

Weighted Decision Matrix – Final Results

Satisfaction Total Score	Cutting	Grooving	Adhesive	Folding	Total Weighted Score
High Satisfaction Option	3	4	2	1	
Score	42.5	48.0	45.5	45.0	181.0
Tape Option 1	3	4	4	1	
Score	42.5	48.0	36.5	45.0	172
Glue Option 1	3	4	2	4	
Score	42.5	48.0	45.5	38.0	174

Master Excel – Cost Analysis



Optimisation of 128 permutations – Proposed solutions

Decision Factors		1 Cutting	2 Grooving	3 Adhesive	4 Fold & Pack	Selection		Adhesive + Pack		Cutting & Groove	21,22...	31,32...	41,42...
Option 1	Satisfaction	32	36	32	45		tape11	76	11	67.5	69	78	76
	Cost	0.05	0.1	0.2	4.1			4.292793333		0.13053	0.11903	0.13803	0.13203
Option 2	Satisfaction	33.5	34	37	35		tape21	81	12	65.5	67	76	74
	Cost	0.04	0.1	0.2	5.1			4.283935		0.11953	0.10803	0.12703	0.12103
Option 3	Satisfaction	42.5	42	45	32		Glue32	79.5	13	74	75.5	84.5	82.5
	Cost	0.06	0.1	0.1	5.1			5.17263		0.13338	0.12188	0.14088	0.13488
Option 4	Satisfaction	40.5	48	46	41		Glue33	76.5	14	80	81.5	90.5	88.5
	Cost	0.05	0.1	0	5.1			5.17638		0.14612	0.13462	0.15362	0.14762
							Glue34	85					
		32	36	45	45			5.17888					
material	500000	4.85	8.2	7.6	405	92.808	Glue42	80.5					
shipping flat	312500	33.5	34	46	35			5.13633					
shipping folded	416500	3.7	7.1	4	510		Glue43	77.5					
power	40000	42.5	42	32	32			5.14008					
conveyor	4000	5.6	8.5	24	510		Glue44	86					
ADD	544000	40.5	48	37	41			5.14258					
		5	9.8	23	510								

	11	21	31	41					
tape11	143.5	145	154	152		14.5489	14.7181	15.6015	15.4083
	4.42332	4.41182	4.43082	4.42482		0	0	0	0
tape21	148.5	150	159	157		15.0693	15.2393	16.1226	15.9294
	4.41446	4.40296	4.42196	4.41596		0	0	0	0
Glue32	147	148.5	157.5	155.5		13.6831	13.8376	14.6503	14.4723
	5.30316	5.29166	5.31066	5.30466		0	0	0	0
Glue33	144	145.5	154.5	152.5		13.3992	13.5533	14.3662	14.1882
	5.30691	5.29541	5.31441	5.30841		0	0	0	0
Glue34	152.5	154	163	161		14.1868	14.3417	15.1531	14.9755
	5.30941	5.29791	5.31691	5.31091		0	0	0	0
Glue42	148	149.5	158.5	156.5		13.8229	13.978	14.7932	14.6148
	5.26686	5.25536	5.27436	5.26836		0	0	0	0
Glue43	145	146.5	155.5	153.5		13.538	13.6927	14.5082	14.3296
	5.27061	5.25911	5.27811	5.27211		0	0	0	0
Glue44	153.5	155	164	162		14.3282	14.4838	15.2976	15.1195
	5.27311	5.26161	5.28061	5.27461		0	0	0	0
	12	22	32	42					
tape11	141.5	143	152	150		14.3621	14.5313	15.4161	15.2225
	4.41232	4.40082	4.41982	4.41382		0	0	0	0
tape21	146.5	148	157	155		14.883	15.0529	15.9375	15.7441
	4.40347	4.39197	4.41097	4.40497		0	0	0	0
Glue32	145	146.5	155.5	153.5		13.5108	13.6652	14.479	14.3008
	5.29216	5.28066	5.29966	5.29366		0	0	0	0
Glue33	142	143.5	152.5	150.5		13.2266	13.3807	14.1947	14.0164
	5.29591	5.28441	5.30341	5.29741		0	0	0	0
Glue34	150.5	152	161	159		14.0151	14.17	14.9824	14.8046
	5.29841	5.28691	5.30591	5.29991		0	0	0	0
Glue42	146	147.5	156.5	154.5		13.6501	13.8052	14.6216	14.4428
	5.25586	5.24436	5.26336	5.25736		0	0	0	0
Glue43	143	144.5	153.5	151.5		13.365	13.5197	14.3363	14.1574
	5.25961	5.24811	5.26711	5.26111		0	0	0	0
Glue44	151.5	153	162	160		14.1561	14.3116	15.1266	14.9482
	5.26211	5.25061	5.26961	5.26361		0	0	0	0

	13	23	33	43					
tape11	150	151.5	160.5	158.5		15.2035	15.3734	16.2553	16.0626
	4.42617	4.41467	4.43367	4.42767		0	0	0	0
tape21	155	156.5	165.5	163.5		15.7244	15.8951	16.7768	16.5841
	4.41732	4.40582	4.42482	4.41882		0	0	0	0
Glue32	153.5	155	164	162		14.2844	14.4394	15.2508	15.0733
	5.30601	5.29451	5.31351	5.30751		0	0	0	0
Glue33	150.5	152	161	159		14.0003	14.155	14.9666	14.789
	5.30976	5.29826	5.31726	5.31126		0	0	0	0
Glue34	159	160.5	169.5	167.5		14.7876	14.9431	15.7531	15.5759
	5.31226	5.30076	5.31976	5.31376		0	0	0	0
Glue42	154.5	156	165	163		14.4262	14.5819	15.3958	15.2177
	5.26971	5.25821	5.27721	5.27121		0	0	0	0
Glue43	151.5	153	162	160		14.1411	14.2964	15.1106	14.9324
	5.27346	5.26196	5.28096	5.27496		0	0	0	0
Glue44	160	161.5	170.5	168.5		14.931	15.0872	15.8997	15.722
	5.27596	5.26446	5.28346	5.27746		0	0	0	0
	14	24	34	44					
tape11	156	157.5	166.5	164.5		15.7912	15.9616	16.8413	16.6491
	4.43891	4.42741	4.44641	4.44041		0	0	0	0
tape21	161	162.5	171.5	169.5		16.312	16.4831	17.3626	17.1705
	4.43006	4.41856	4.43756	4.43156		0	0	0	0
Glue32	159.5	161	170	168		14.8251	14.9806	15.7901	15.613
	5.31875	5.30725	5.32625	5.32025		0	0	0	0
Glue33	156.5	158	167	165		14.5412	14.6963	15.506	15.3289
	5.3225	5.311	5.33	5.324		0	0	0	0
Glue34	165	166.5	175.5	173.5		15.3275	15.4833	16.2915	16.1148
	5.325	5.3135	5.3325	5.3265		0	0	0	0
Glue42	160.5	162	171	169		14.9686	15.1247	15.9367	15.7591
	5.28245	5.27095	5.28995	5.28395		0	0	0	0
Glue43	157.5	159	168	166		14.6837	14.8394	15.6516	15.474
	5.2862	5.2747	5.2937	5.2877		0	0	0	0
Glue44	166	167.5	176.5	174.5		15.4725	15.6291	16.4397	16.2625
	5.2887	5.2772	5.2962	5.2902		0	0	0	0

Machine Spec Sheets

Value Engineering – Groove Cutting Stage	
Option #: 1	**Title: MultiCam – High Speed Digital Express**
Description:	Groove cutting with a single 45 angle tangential knife Profile cutting with an oscillating knife **Workspace Size:** 80” x 168” **Max. Cutting Speed**: 3000 IPM **Max. Rapid Traverse**: 7000 IPM **Components:** 1 x D306-K High Speed Digital Express (80 Inch by 168 Inch Work Area) AC servo drives, phenolic grid top 1 x System Includes MultiCam EZ Control and EZ Suite Software 1 x Umbra 3 HP HSK 25 Pneumatic Chuck spindle (ER16 / 50000 rpm), 8 Tool Linear ATC, Heat Exchange 8 Tool Holder 1 x Assy Laser Pointer Cross-hair 12mm Red 10mW (For Easy Soft Homing) 1 x Med Pressure - Phenolic 4 zone (grid) (with pneumatic valves) & Basic Plumbing Kit 1 x 35 HP 2 Stage Regenerative Blower w/ valve and filter (13 Inches hg 780 cfm) 208/230 3 phase 1 x 1.5 M X 25 M Roll - felt sacrificial cutting surface 1 x Advanced Knife Operations Suit 4 2 x Tangential knife cartridge receiver N23 (Digital Express) 1 x DE Standard Knife Cartridge 2 x DE 8mm Knife Holder (Short Holder for Long Blades) 1 x DE Utility Knife Blade Knife Holder 1 x DE Oscillating Knife Cartridge 1 x DE 45 deg Utility Knife Blade Knife Holder 1 x 4 position Linear ATC for Digital Express Knife cartridges 1 x Comprehensive Installation and Training
Advantages:	High Speed feed (one of the fastest on the market)
Disadvantages:	- No multi tool carriages - Slower cutting method with tangential knife - No large chip removal system
Pictures:	
Web Links:	http://www.multicam.com/cncknife.html

<table>
<tr><td colspan="2">Value Engineering – Groove Cutting Stage</td></tr>
<tr><td>Option #: 2</td><td>Title: MultiCam – 3000 Series CNC Machine</td></tr>
<tr><td>Description:</td><td>Groove cutting with a single 45 angle tangential knife
Profile cutting with an oscillating knife

Workspace Size: 80” x 144”
Max. Cutting Speed: 1400 IPM Max. Rapid Traverse: 2500 IPM
Components:
1 x 3305-R-PF (No Spindle) (80 Inch by 144 Inch Work Area)
1 x System Includes MultiCam EZ Control and EZ Suite Software
1 x Assy Laser Pointer Cross-hair 12mm Red 10mW (For Easy Soft Homing)
1 x Med Pressure - Phenolic 4 zone (grid) (with pneumatic valves) & Basic Plumbing Kit with additional Second 1 x Grid
1 x Pop Up Material Location Pins
1 x 17 HP 2 Stage Regenerative Blower w/ valve and filter (13 Inches hg 335 cfm) 208/230 3 phase
1 x Dual tangential knife cartridge receiver (DE Style) (5000 Series)
1 x DE Oscillating Knife Cartridge
2 x DE Standard Knife Cartridge
2 x DE 8mm Knife Holder (Long Holder for Short Blades)
1 x DE 45 deg Utility Knife Blade Knife Holder
1 x DE Utility Knife Blade Knife Holder</td></tr>
<tr><td>Advantages:</td><td>Lower price</td></tr>
<tr><td>Disadvantages:</td><td>- No multi tool carriages
-Slower cutting method with tangential knife
- No large chip removal system</td></tr>
<tr><td>Pictures:</td><td>
</td></tr>
<tr><td>Web Links:</td><td>http://www.multicam.com/3000cncrouter.html</td></tr>
</table>

Value Engineering – Groove Cutting Stage	
Option #: 3	**Title: AXYZ International – 5010 CNC Router**
Description:	Groove cutting with V-bit router Profile cutting with oscillating knife **Workspace Size:** 72” x 120” **Standard Cutting Speed:** 1000 IPM **Components:** - 1 x 5010 CNC Router - 1 x ATC Automatic Tool Changer - 1 x Carriage - 1 x Gantry - 1 x Head carriage - 1 x Collet Spindles - 1 x Oscillating Knife - 1 x Pop-up Location Pins - 1 x Universal 5Y Pressure Foot (The Nose Rider Collar) - 1 x ACM Chip Collection System - 1 x Becker Dry Van Vacuum Hold Down Pump
Advantages:	-Fast Router cut -Waste chip removed
Disadvantages:	-Smaller working space
Pictures:	
Web Links:	http://www.axyz.com/us/axyz-5000-series/

Value Engineering – Groove Cutting Stage	
Option #: 4	**Title: AXYZ International – 5016 CNC Router**
Description:	Pendulum process system Groove cutting with 2 V-bit routers in parallel Profile cutting with 2 oscillating knife in parallel **Workspace Size:** 72” x 192” **Standard Cutting Speed:** 1000 IPM **Components:** - 1 x 5016 CNC Router - 2 x ATC Automatic Tool Changer - 2 x Carriage - 1 x Gantry - 2 x Head carriage - 2 x Collet Spindles - 2 x Oscillating Knife - 1 x Pop-up Location Pins - 2 x Universal 5Y Pressure Foot (The Nose Rider Collar) - 1 x ACM Chip Collection System - 1 x Becker Dry Van Vacuum Hold Down Pump
Advantages:	-Two tool carriages -Fast Router cut -Waste chip removed -Large workspace allowing for Pendulum Process
Disadvantages:	
Pictures:	
Web Links:	http://www.axyz.com/us/axyz-5000-series/

Value Engineering – Option Evaluation Template	
Option #: 1	**Title: LS 373 Pneumatic Spray Gun**
Description:	The LS 373 pneumatic spray gun provides high-precision spray capability through adjustable dual-air pressure and adhesive volume control. The innovative nozzle design delivers precise, wide spray patterns with a broad range of adhesives and is particularly suited for packaging and folding carton applications.
Advantages:	Evenly covers whole surface, accommodates wide viscosity range, maintains high tolerance, gives accurate adhesive volume control.
Disadvantages:	Less open time
Pictures:	
Web Links:	http://www.nordson.com/EN-US/DIVISIONS/ADHESIVE-DISPENSING/PRODUCTS/LIQUID-ADHESIVE-APPLICATORS/Pages/LS373-SprayGun.aspx

Rating
assign a score from 1 to 5 for each, where 5 is best and 1 is worst.

	Level of Automation	Quality	Reliability
Score	5	5	5

Value Engineering – Option Evaluation Template	
Option #: combine with option 1	**Title: LA 300 Piston Pump**
Description:	Efficient pump systems provide consistent delivery of liquid adhesives and maximize production flexibility.
Advantages:	Removes contaminants, resists corrosion, constant delivery, easily adaptable
Disadvantages:	
Pictures:	
Web Links:	http://www.nordson.com/en-us/divisions/adhesive-dispensing/Literature/PKL/PKL-04-3268-LA-300-Pumps.pdf

Rating
assign a score from 1 to 5 for each, where 5 is best and 1 is worst.

	Level of Automation	Quality	Reliability
Score	5	5	5

Value Engineering – Option Evaluation Template	
Option #: 2	**Title: Mini Blue II Hot Melt Dispensing Applicator**
Description:	Hot Melt Glue Bead Applicator
Advantages:	Longest life of any pneumatic applicator, high speed, more open time, energy/resource efficient, minimal downtime
Disadvantages:	Brittle, less evenly spread, narrow line of glue
Pictures:	
Web Links:	http://www.nordson.com/en-us/divisions/adhesive-dispensing/products/Hot-Melt-Applicators-Pneumatic/Pages/MiniBlue-HotMelt-DispensingGuns.aspx

Rating
assign a score from 1 to 5 for each, where 5 is best and 1 is worst.

	Level of Automation	Quality	Reliability
Score	5	5	5

Value Engineering – Option Evaluation Template

Option #: combine with option 2	**Title: Alta Blue TT Adhesive Melter**
Description:	Melter for hot melt glue applications
Advantages:	Easy to install, easy operation, simple maintenance, easy controls, easy to see displays.
Disadvantages:	
Pictures:	
Web Links:	http://www.nordson.com/EN-US/DIVISIONS/ADHESIVE-DISPENSING/PRODUCTS/HOT-MELT-ADHESIVES-SYSTEMS/Pages/AltaBlueTT-Melters.aspx

Rating

assign a score from 1 to 5 for each, where 5 is best and 1 is worst.

	Level of Automation	**Quality**	**Reliability**
Score	5	5	5

Value Engineering – Option Evaluation Template	
Option #: 3	**Title: T-627-1**
Description:	Double sided tape applicator
Advantages:	Lower price
Disadvantages:	Slower speeds, less heavy duty
Pictures:	
Web Links:	http://www.straubdesign.com/~straubde/sites/default/files/T-627%20Tape%20Applicator.pdf

Rating
assign a score from 1 to 5 for each, where 5 is best and 1 is worst.

	Level of Automation	Quality	Reliability
Score	4	4	4

Value Engineering – Option Evaluation Template

Option #: 4	**Title: T-626**
Description:	Double sided Tape Applicator
Advantages:	More flexible, faster, tougher
Disadvantages:	More expensive, overkill
Pictures:	
Web Links:	http://www.straubdesign.com/~straubde/sites/default/files/T-626%20Tape%20Applicator.pdf

Rating
assign a score from 1 to 5 for each, where 5 is best and 1 is worst.

	Level of Automation	**Quality**	**Reliability**
Score	4	5	5