

# A Process Evaluation and Cost Benefit Analysis Investigating the Implementation of CNC based Manufacturing for the Production of Solid Wood Doors at Unison Windows and Doors

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## **Abstract**

Unison Windows and Doors is a company located on the North Shore of Vancouver which specializes in the manufacturing of solid wood windows and doors. Their current door manufacturing process involves the use of conventional machinery such as table saws, planers and shapers to craft each piece required for door assembly. An opportunity has been identified to optimize the existing manufacturing process by the implementation of Computer Numerical Controlled (CNC) machining to automate the door production process. The proposed CNC router will function to produce the various components required for door assembly. This paper will compare the current manufacturing process with a new proposed process. In addition, it will identify requirements for the implementation of the CNC router including the tools required to perform the machining, the methods of orientating the pre-machined components on the CNC's table, and time estimates of the new processes. A cost benefit analysis of purchasing the CNC machine will be conducted using three popular engineering economic models. A discussion of the current market trends and forecasts for the future growth or decline of the market will be outlined. The advantages and disadvantages of the new process will be explored, and a specific model of CNC router will be suggested.

## 1 Glossary of Terms

Door Frame – The part of the door that fits into the walls opening. The door slab is attached to the door frame.

Jamb – Three pieces of wood material that make the doors frame.

Lock Jamb – The vertical piece of jamb that is located opposite the doors lock.

Hinge Jamb – The vertical piece of jamb that the doors hinges attach to.

Top Jamb – The horizontal piece of jamb that is located at the top of the doors frame.

Sill – A piece of wood that is located at the bottom of the door frame and runs parallel to the floor.

Door Slab – The door assembly made up of the rails, the stiles, and the panel.

Rail – Horizontal door slab components that fit between the stiles.

Stile – The two vertical wood components that make up the sides of the door slab.

Rabbet – A joint used to connect to perpendicular pieces of wood at their ends.

Lite – The space in the door where a glass panels fits into.

Jig – A device built in order to guide a tools path.

Latch Mechanism – A mechanical device used to secure the door slab to the door frame when the door is in a closed position.

CNC Machine Table – The working area of the CNC machine. It can be a flat table bed or movable positioning arms.

Machine Reference Pins – Circular pins used to position components on the CNC machine. Typically two edges are butted up against two pins to assure the operator that the components have been loaded correctly.

Machine Suction Pots – Pneumatic devices used to hold components down during CNC tooling. They engage when the machines vacuum system is turned on.

Mortiser - A horizontal or vertical router or drilling machine used to machine holes or pockets into solid wood.

## **2 Introduction**

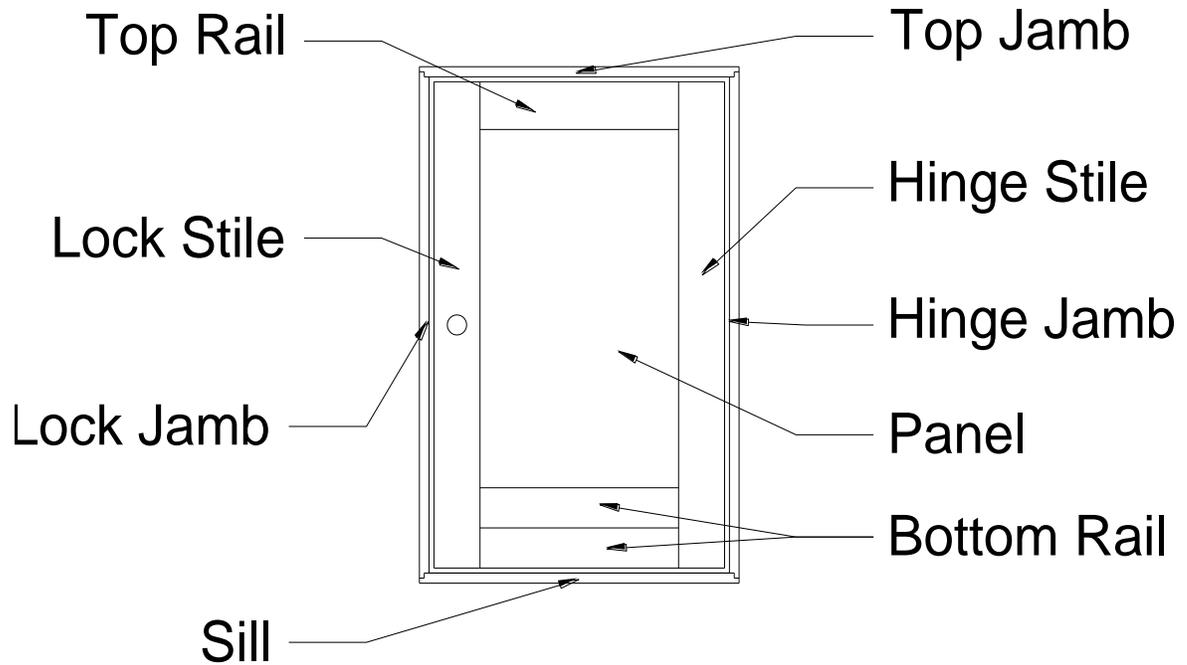
The purpose of this paper is to determine if a manufacturer of solid wood doors can benefit from investing in a CNC router in order to automate some of the processes used to manufacture the doors components. Throughout the paper traditional manufacturing methods using standard machinery (panel saws, thickness planers, and shapers) will be compared and contrasted with new methods implementing advanced technology. The current procedure to manufacture a French Swing door used by Unison Windows and Doors will be examined, and a new procedure involving the production of the doors components using a CNC router will be explored. After both manufacturing processes are examined a detailed analysis of the economic feasibility of the purchase of a new CNC router will be conducted. This will be followed by a discussion of the positive and negative aspects of altering the current process. There will also be a brief market analysis of the upcoming trends and expected market growth patterns of the solid wood door industry to ensure that a market for solid wood doors is both available and growing in order to justify investing in new technology. The door examined in this evaluation will be a five piece solid wood door with stile and rail construction. These types of doors are used in a variety of applications ranging from kitchen cabinets to interior and exterior doors found in residential housing and commercial buildings. Unison Windows and Doors manufacture a French Swing door that utilizes a five piece stile and rail construction.

## **3 Current Door Production Process**

### *3.1. The components involved in the door manufacturing process*

There are two main components that are required in order for the door to be installed into the door opening and to function. They are the door frame, and the door slab. The door frame is made up of three pieces of wood referred to as jamb, and one piece of wood referred to as the sill. The piece of jamb that fits horizontally at the top of the opening will be referred to as the

top jamb, and the two pieces of jamb that fit vertically along the sides of the opening will be referred to as the lock jamb and the hinge jamb. The bottom piece of the frame that fits along the floor of the house is referred to as the sill. The door slab is composed of five components. The two components that make up the vertical sides of the door slab are called the stiles. The stile where the door handle hardware is to be installed is called the lock stile, and the stile where the door hinges are attached is called the hinge stile. The top and bottom of the door slab is made up of two components called rails. The rail that is located at the top of the door slab is called the top rail, and the rail that is located at the bottom of the door slab is called the bottom rail (see figure 1.). In some cases a larger bottom rail is desired. To achieve this two bottom rails are edge glued together. The final component is the doors panel which fits between the stiles and the rails and makes up the remainder of the doors construction. For the French swing door the panel is glass. The door slab is attached to the door frame via hinges. The hinges are attached to the hinge stile and the right side jamb.



**Figure 1. French Door Components**

### *3.2. The current steps and material flow in the existing manufacturing process*

#### **3.2.1. Material Selection**

The first step in the doors manufacturing process is the selection of a material that the door will be made from. The frame of the French Swing door is currently constructed from Douglas-Fir unless otherwise specified. Jamb and Sill material are ordered pre-machined and are stored in Unisons inventory section of its facility. Sill material may need some modifications depending on the customer's specifications. The material to be used to construct the door slab will be ordered if it is not currently in stock. If the door is to be manufactured using a high quality expensive hardwood, such as Black Walnut or Cherry, a Douglass-Fir core may be used to both save material costs and increase dimensional stability. Dimensional stability can be increased by changing the grain direction of the core

so it alternates to the grain direction of the outer door pieces (see figure 2). If the material is not on hand it will be ordered and delivered to Unisons receiving bay where it will be sorted, graded, and its moisture content verified.



**Figure 2. Black Walnut Door with a Douglas-Fir Core (Unison Windows and Doors)**

### 3.2.2. Manufacture the Components for the Door Frame

If the material to build the frame is available in inventory then frame construction can begin immediately. A typical one lite French Swing door at Unison Windows and Doors will measure 762 mm by 2032 mm. The doors frame requires three pieces of 167 mm wide jamb with one piece of 200 mm wide sill (Barlow, 2011). The door slab requires two 122 mm wide stiles, one 122 mm wide top rail, and one 219 mm wide bottom rail (Barlow, 2011).

If the door uses a stick coping system (see figure 3), which matches the end profile of the rails to the edge profile of the stiles, then these profiles will need to be machined . Each stile will require a coping profile and each rail a complimentary stick



**Figure 3. Stick Coping System (Rockler)**

profile which are typically created using a shaper and profiling router bit. (Rockler) Unison Windows and Doors do not use this type of system. Instead they use what Jordan Barlow, the production engineer, refers to as a "lap joint" (Barlow, 2011). This is where a rabbet joint (see figure 4.) is machined for the glass panel to fit in the doors lite, and a piece of glazing bead is attached on the other side of the glass panel. The glazing bead is attached using glazing tape and nails. This rabbet joint is machined on the shaper and the glazing bead is pre-manufactured and stored in inventory. The steps to machine the door components are as follows:

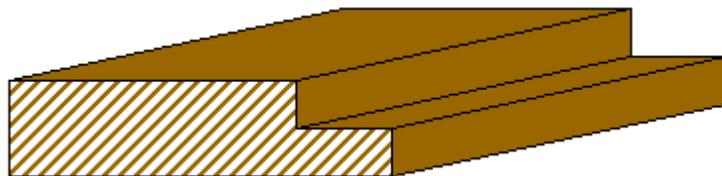


Figure 4. Example of a Rabbet Joint (Wikipedia, 2011)

### Top Jamb

The top jamb comes pre-cut to a width of 167 mm and a thickness of 32 mm with a 67 mm rabbet notched in place so no machining is necessary for these dimensions.

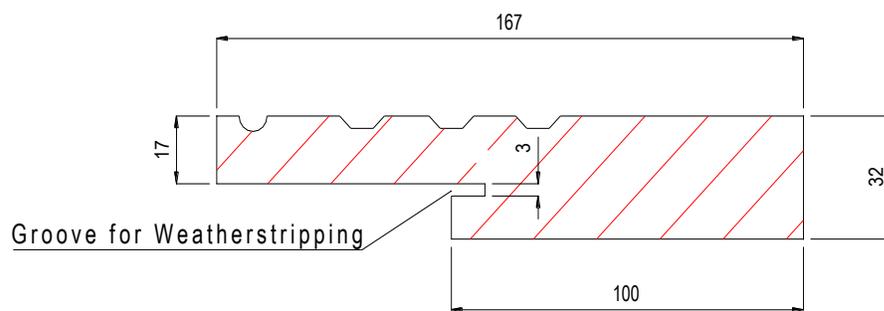


Figure 5. Top Jamb (Barlow, 2011)

### Steps to manufacture the Top Jamb

1. The top jamb is cut to a length of 797 mm using the table saw.

2. A 10 mm long by 3 mm wide groove is cut to accommodate the weather stripping using the table saw.

### Side Jamb

The side jamb comes pre-cut to a width of 167 mm and a thickness of 32 mm with a 67 mm rabbet notched in place so no machining is necessary for these dimensions.

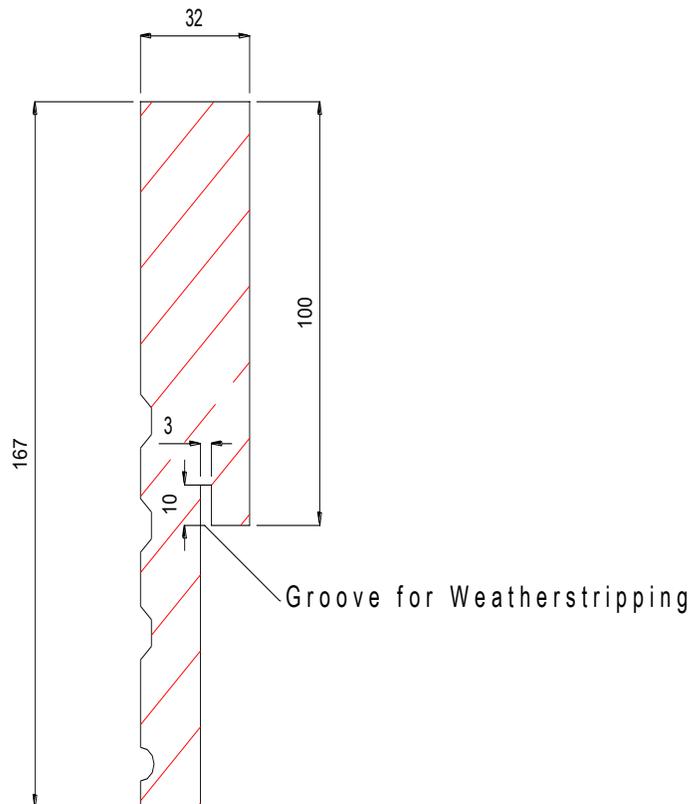


Figure 6. Side Jamb (Barlow, 2011)

### Steps to Manufacture the Lock Jamb and Hinge Jamb

1. The lock jamb and hinge jamb are cut to a final length of 2070 mm using the table saw.

2. A 10 mm long by 3 mm wide groove is cut to accommodate the weather stripping using the table saw.
3. A 16 mm by 167 mm Rabbet is cut on the top and bottom ends of the jamb using the table saw.

### Sill

The sill comes pre-machined to the dimensions seen in figure 7.

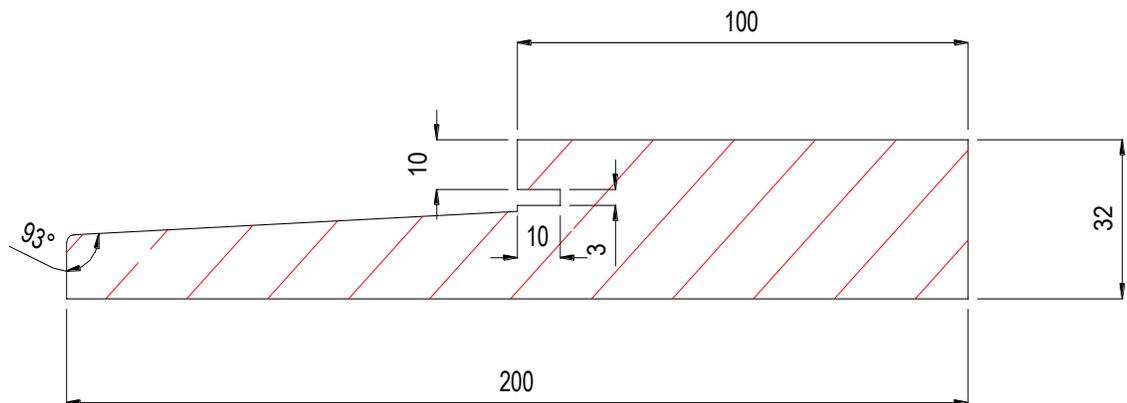


Figure 7. The Sill (Barlow, 2011)

### Steps to Manufacture the Sill

1. The sill is cut to a length of 1137 mm using the table saw.
2. A 10 mm long by 3 mm wide groove is cut to accommodate the weather stripping using the table saw.

### 3.2.3. Hinge and latch hardware preparation of the lock jamb and hinge jamb

#### Hinge Jamb

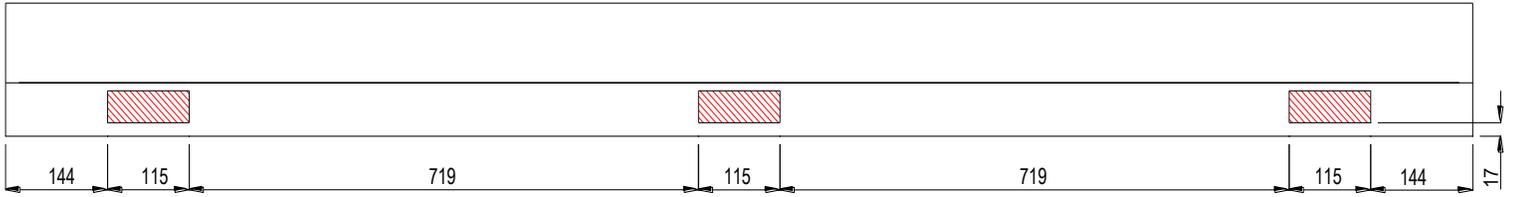


Figure 8. Hinge pocket preparation

#### Steps for hinge preparation of the hinge jamb

1. Two 115 mm by 40 mm pockets are machined 144 mm from the ends of the lock jamb using a premade jig and a mortiser.
2. One 115 by 40 mm pocket is machined 978 mm from the end of the lock jamb using a premade jig and a mortiser.

#### Lock Jamb

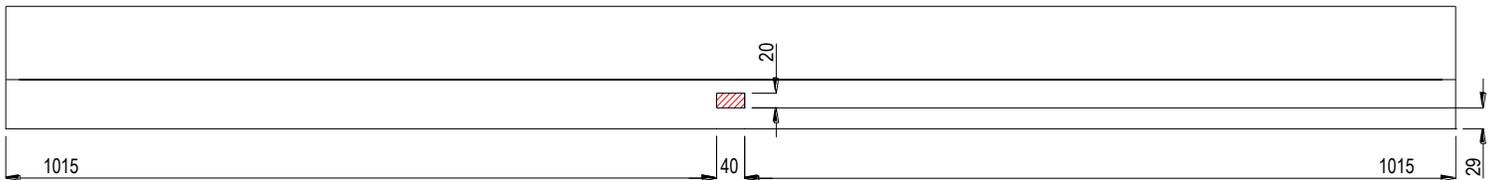


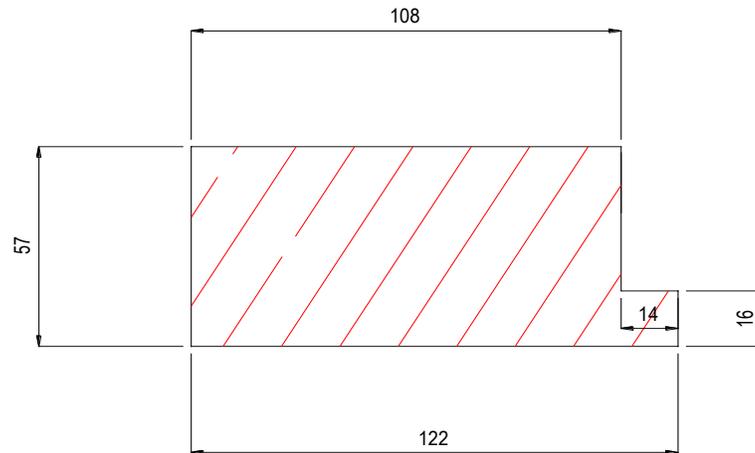
Figure 9. The hole required for the latch mechanism in the lock jamb

#### Steps for latch preparation of the lock jamb.

1. A 20 by 40 mm pocket is machined out of the lock jamb using a premade jig and a mortiser.

### 3.2.4. Manufacture Components for the Door Slab

#### Stiles



**Figure 10. Left and Right Stiles (Barlow, 2011)**

#### Steps to manufacture the Left and Right Stiles

1. The stile is cut to a length of 2032 mm using the table saw.
2. The stile is cut to a width of 122 mm using the table saw.
3. The stile is machined to a thickness of 57 mm the thickness planer.
4. A 41 mm by 14 mm rabbet is cut into the stile using the shaper.

## Rails

### Top Rail

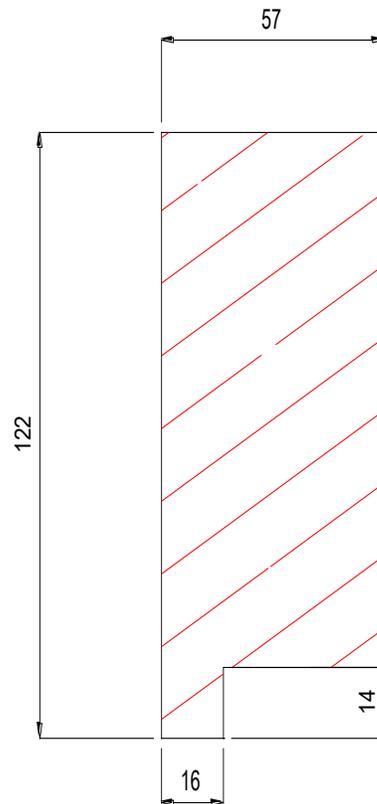


Figure 11. Top Rail (Barlow, 2011)

### Steps to manufacture the top rail

1. The rail is cut to a width of 122 mm using the table saw.
2. The rail is cut to a length of 550 mm long using the table saw.
3. The rail is machined to a thickness of 57 mm using the thickness planer.
4. A 41 mm by 14 mm rabbet is cut into the stile using the shaper.

## Bottom Rail

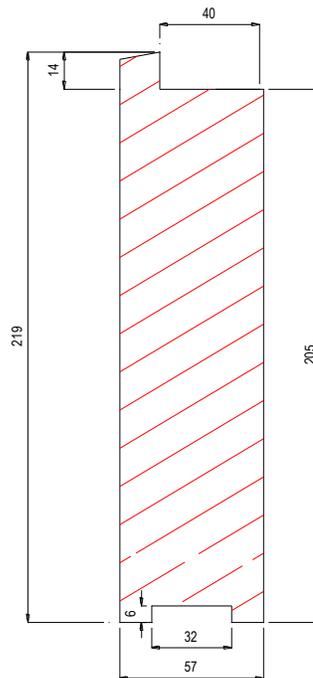


Figure 12. Bottom Rail (Barlow, 2011)

### Steps to manufacture the bottom rail

1. The bottom rail is cut to a length of 550 mm using the table saw.
2. The bottom rail is cut to a width of 219 mm using the table saw.
3. The rail is machined to a thickness of 57 mm using the thickness planer.
4. A 41 mm by 14 mm rabbet is cut out of the top end of the rail using the shaper
5. A 32 mm by 6 mm pocket to machined out of the bottom end of the rail using the shaper. This pocket will hold the weather stripping at the bottom of the door called the door sweep. (Barlow, 2011)

#### 3.2.5. Machining dowel holes

The stiles and rails are connected using 16 mm dowels (Barlow, 2011). This will require three dowel holes to be machined on the ends of each rail and 9 dowel holes on the inside

face of each stile (see figure 13). The dowel holes are drilled 32 mm apart using a mortiser and jig. (Barlow, 2011)

### Drilling Dowel Holes in Stiles

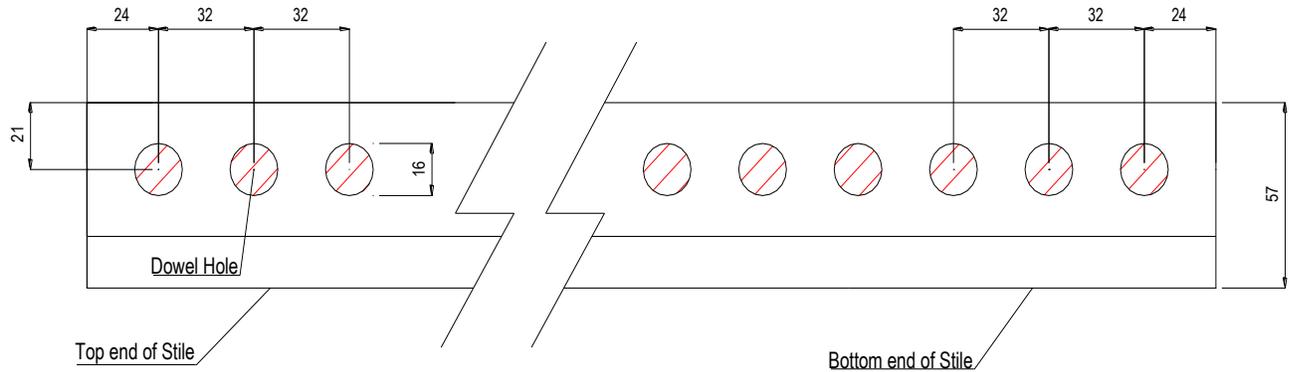


Figure 13. Left and Right Stile dowel hole placement

### Steps to drill dowel holes in stile.

1. A mortiser is set up with a 16 mm drilling bit with and 32 mm spacer jig.
2. The first hole is drilled 24 mm from the top end and 21 mm from the right edge of the lock stile as seen in figure 10.
3. The second hole is drilled 32 mm to the left of the first hole using the jig as reference.
4. The third hole is drilled third 32 mm to the left of the second hole.
5. The stile is then moved so the bottom end is lined up with mortise and jig.
6. The first hole is drilled 24 mm to the right of the bottom end of the stile.
7. The second hole is drilled 32 mm to the right of first hole using the jig as reference.
8. This process is repeated until six dowel holes are drilled in bottom end of stile.
9. The entire process is repeated on the inside face of the hinge stile.

## Drilling Dowel Holes in Top Rail

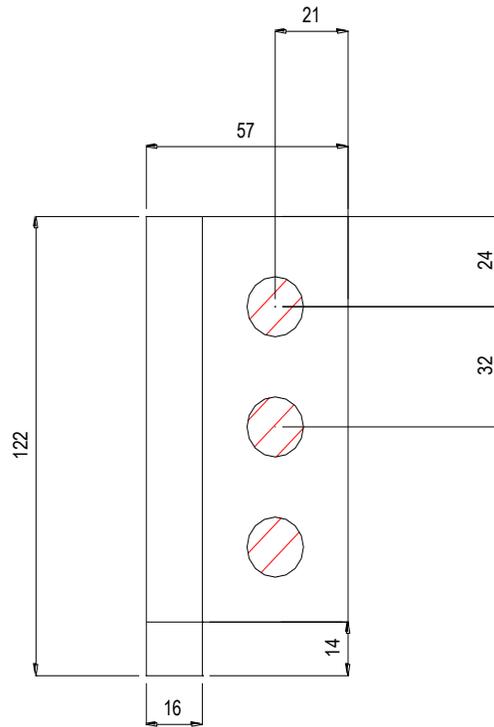


Figure 14. Top Rail Dowel Hole Placement

### Steps to drill dowel holes in the Top Rail

1. A mortiser is set up with a 16 mm drilling bit with and 32 mm spacer jig.
2. A hole is drilled using the mortiser 24 mm from the top end of the rail and 21 mm from the right end of the rail as seen in figure 11.
3. A second hole is drilled using the mortiser 32 mm below the first hole as per the spacing on the jig.
4. A third hole is using the mortiser 32 mm below the second hole.
5. The process is then repeated on the other end of the rail.

## Drilling Dowel Holes in Bottom Rail

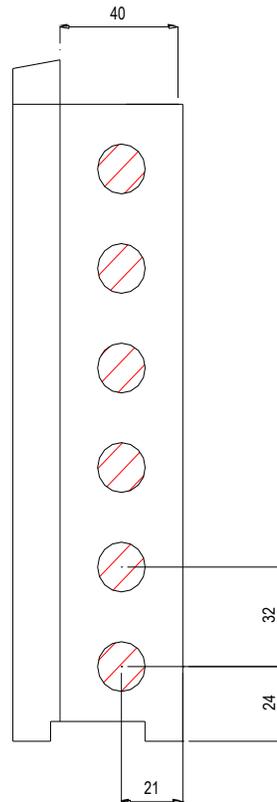


Figure 15. Bottom Rail Dowel Hole Placement

### Steps to drill dowel holes in the bottom rail

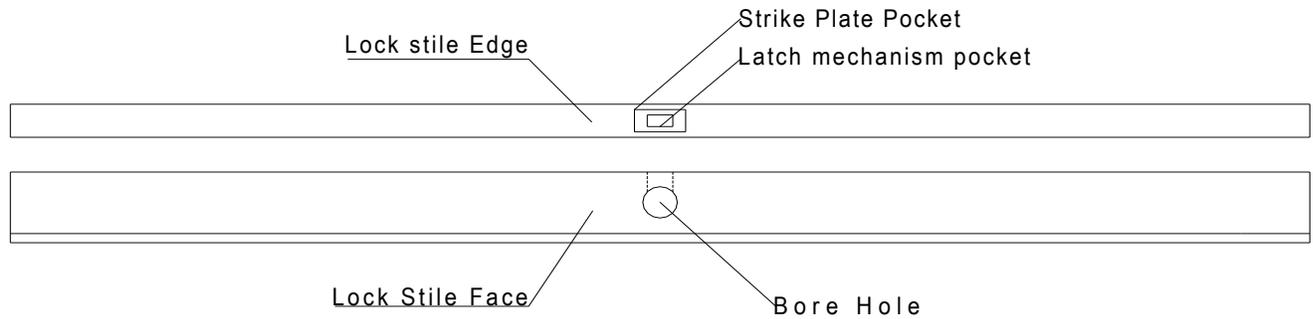
1. A mortiser is set up with a 16 mm drilling bit with and 32 mm spacer jig.
2. A hole is drilled using the mortiser 24 mm from the bottom end of the rail and 21 mm from the right end of the rail as seen in figure 11.
3. A second hole is drilled using the mortiser 32 mm above the first hole as per the spacing on the jig.
4. This process is repeated until 6 dowel holes have been drilled on the end of the rail.
5. The process is then repeated on the other side of the rail.

### 3.2.6. Door assembly and Gluing

After the components are machined the door is then assembled without glue to ensure the dowel holes on the ends of the rails line up properly with the dowel holes on the edge faces of the stiles. If the door pieces do not fit they are re-machined. If the door is not square some of the fittings are adjusted. Once everything fits together properly the components are glued and held in place with vices for the glue to set. After the glue has been cured the door is then examined to ensure that it is square. A 3 mm bevel is then machined in all the outside facing edges of the door components using the shaper.

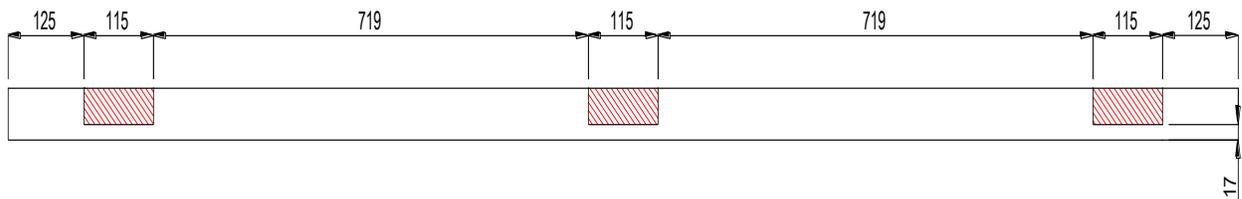
### 3.2.7. Pocket construction for knob and handle hardware

Two mechanisms are required for the door hardware to function. They are referred to as the door knob and the latch mechanism. The door knob is the handle that is turned to operate the latch mechanism. The latch mechanism is used to secure the door to the door frame when the door is in a closed position. The door knob is usually placed halfway up the door (see figure 16). The size and shape of the hole required for the door knob to fit in the door is determined by the door hardware. This hole is referred to as the bore hole (Barlow, 2011). A pocket will also be needed for the latch mechanism and will be placed on the left face of the lock stile facing the door frame. Another pocket will be needed to house the strike plate for the latching mechanism. The door latch mechanism pocket and the door knob bore hole intersect (see figure 16). To machine the holes and matching pockets measurements are drawn on the stiles faces and a mortise and jig is used. Various jigs are used to ensure alignment. New jigs are often constructed to accommodate various door handle/latch systems (Barlow, 2011).



**Figure 16. Door Handle hardware hole and latch mechanism pocket on lock stile**

Pockets are also required on the hinge stile in order for the hinges to lay flush against the stile. Jigs are constructed to align the placement of these pockets and the material is removed using a hand chisel.



**Figure 17. Hinge hardware pocket locations on hinge stile**

### 3.3. Identify the current manufacturing capacity and bottlenecks

Currently, the largest bottleneck in the manufacturing process is the placement and drilling of the dowel and bore holes. This is due to the precise nature regarding the placement of the holes, and the need to manufacture custom jigs. Another bottleneck is preparing the hinge stile and right side piece of jamb for hinge placement. (Barlow, 2011). Over time jigs become worn and less accurate. If the jig is not accurate due to over-use, or the component being machined is placed in the jig inaccurately, the dowel holes or door hardware will not line up and the stile or

rail will have to be remanufactured. Remanufacturing is currently a large portion of the doors production time (Barlow, 2011). The times to produce the door components using the current manufacturing process are as follows:

**Table 1. Time estimates of current door manufacturing process (Barlow, 2011)**

<b>Process Description</b>	<b>Time (minutes)</b>
<b>Cut top jamb, lock and stile jamb, and sill to size</b>	20
<b>Machine the rabbet into the lock and stile jamb</b>	5
<b>Cut stiles and rails to size</b>	20
<b>Machine the rabbet in the rails and stiles for the glass panel</b>	5
<b>Machine the rabbet in the ends of the rails for the stile profile</b>	5
<b>Drill the Dowel holes</b>	10
<b>Machine the a bevel onto the door slab</b>	5
<b>Machine a sweep onto the door</b>	5
<b>Machine pockets for hinges on hinge stile and hinge rail.</b>	20
<b>Drill Bore hole and latch set pocket</b>	60
<b>Total</b>	155

The entire time needed to manufacture all the components for a door slab using the current process is 155 minutes.

## **4 Newly proposed manufacturing process to include CNC routing**

### *4.1. Select door components for CNC production.*

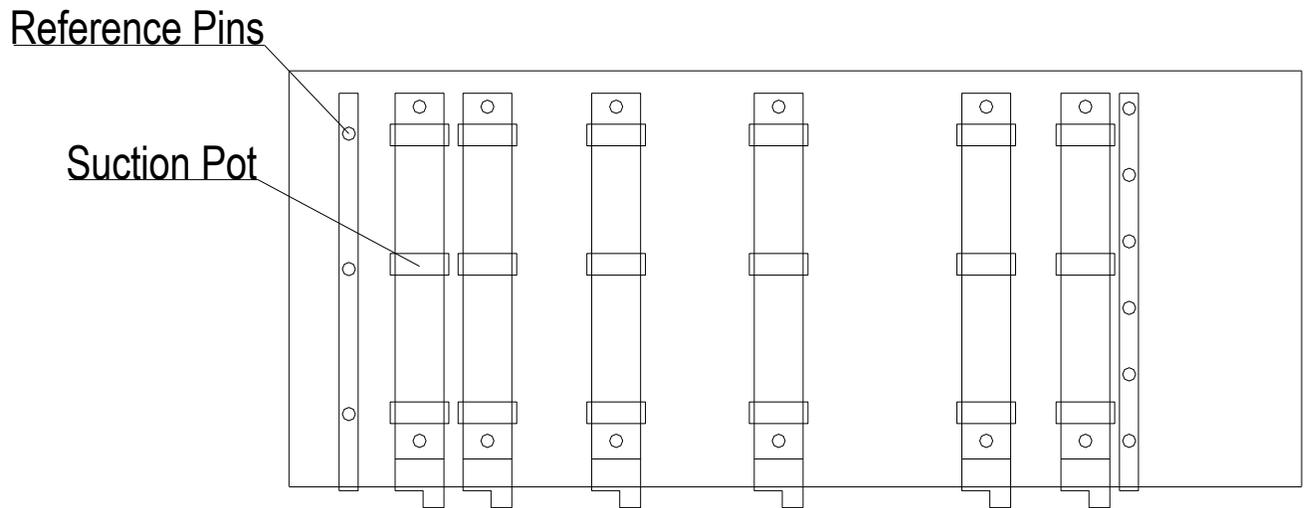
The rails and stiles that make up the door slab assembly are prime candidates for CNC machining. This is due to the precision needed to accurately install the door hardware and to align the lock and hinge stiles dowel holes with the top and bottom rails dowel holes. The precise placement necessary for the door knob hardware, the bore hole on the lock stile, and the hardware screw holes that are required for the hinges also make the stiles and rails attractive candidates for CNC production. The same is true regarding the lock jamb and hinge jamb. Using CNC manufacturing will reduce the time that is needed to align the dowel holes and pockets for the door knob and handle hardware. This is because it will no longer be necessary to manufacture jigs needed to align the hinges, place the bore hole, or drill the dowel holes.

### *4.2. Define the new steps to the manufacturing process and material flow to CNC routing.*

The Lock Jamb and Hinge Jamb components of the Door frame are machined after they have been initially cut to final dimensions using the table saw. Since the Jamb is bought pre-milled, no other machining is necessary except for the placement of the pocket for the latch mechanism in the lock jamb, and the pockets for the hinge placement in the hinge jamb. (Barlow, 2011)

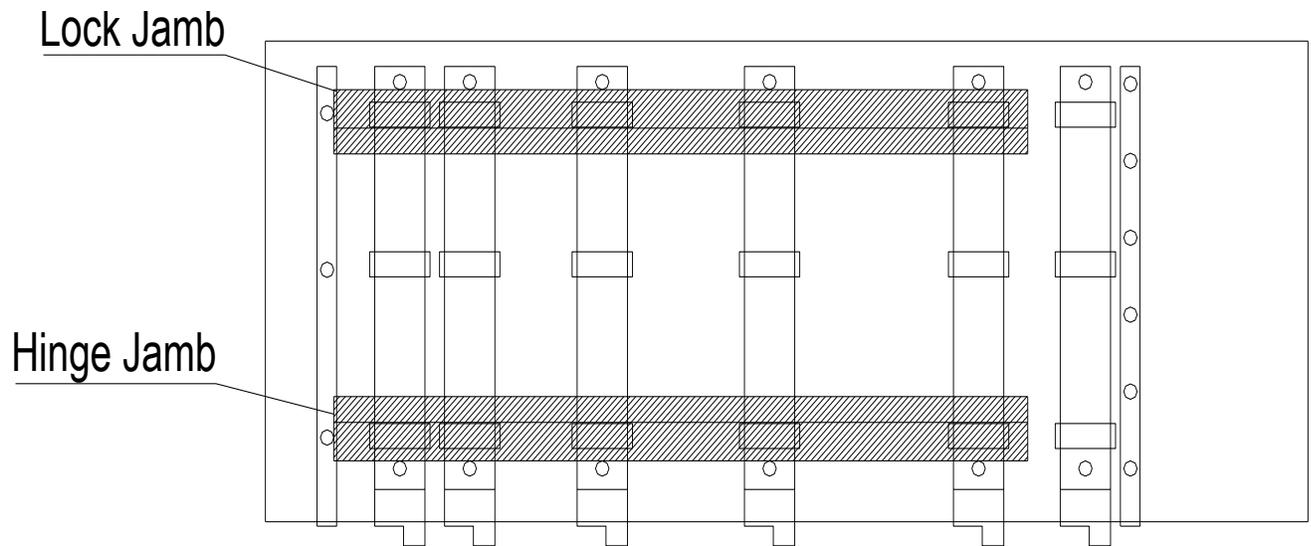
#### **The steps required to machine the lock and hinge jamb components**

1. The program to machine the lock and hinge jamb components is loaded onto the machine.
2. The pots and reference pins are put into position as seen in figure 18.



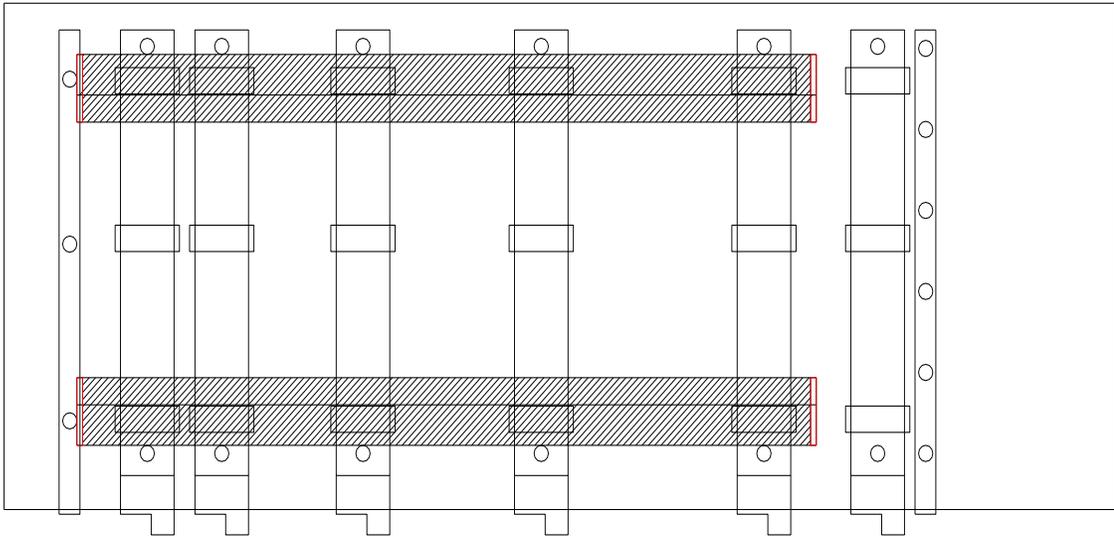
**Figure 18. Positioning of Tubeless Vacuum arms, Suction Pots and Reference Pins.**

3. Load the components onto the machine.



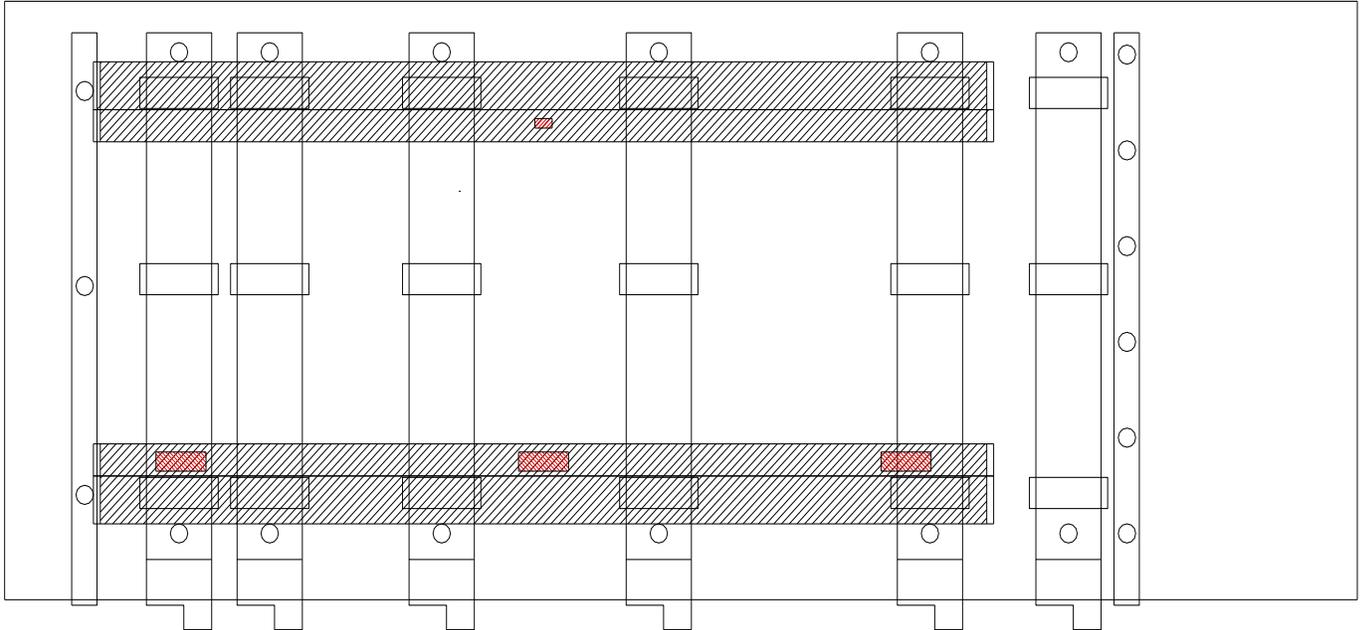
**Figure 19. Lock Jamb and Hinge Jamb components positioned on the suction pots using reference pins**

4. The suction is turned on and the reference pins drop.
5. A 16 mm x 167 mm Rabbet onto the ends of the lock jamb and hinge jamb using a 19.5 mm router bit.



**Figure 20. Tool path for rabbet on Lock Jamb and Hinge Jamb outlined in red**

6. A 20 mm by 40 mm rectangular hole is machined into the lock jamb for the latch mechanism, and three 115 mm by 40 mm by 5 mm pockets are machined into the hinge jamb using a 19.5 mm router bit.



**Figure 21. Placement of latch mechanism hole and hinge hardware pockets on Lock Jamb and Hinge Jamb**

7. The suction is turned off.
8. The Components are offloaded from the machine table.

#### **Steps required to Machine the Door Slab Components**

1. The program to machine the door slab components is loaded on the machine
2. The pots and reference pins are put into position as shown in figure 22.

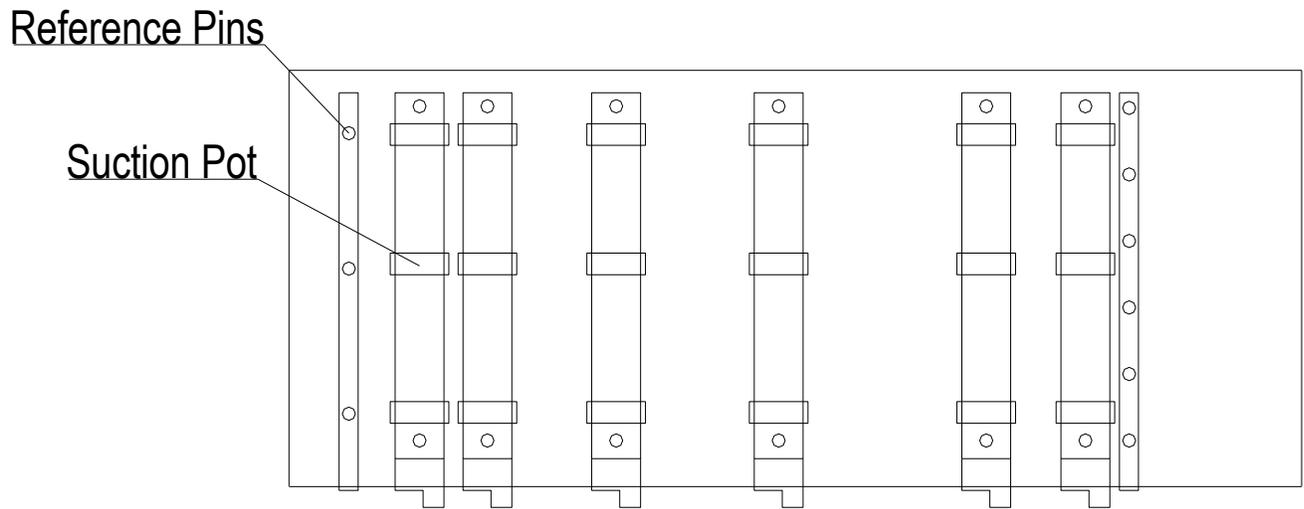


Figure 22. The Layout of the CNC Table showing the positioning of the suction pots and reference pins.

3. The pieces are loaded onto the machine

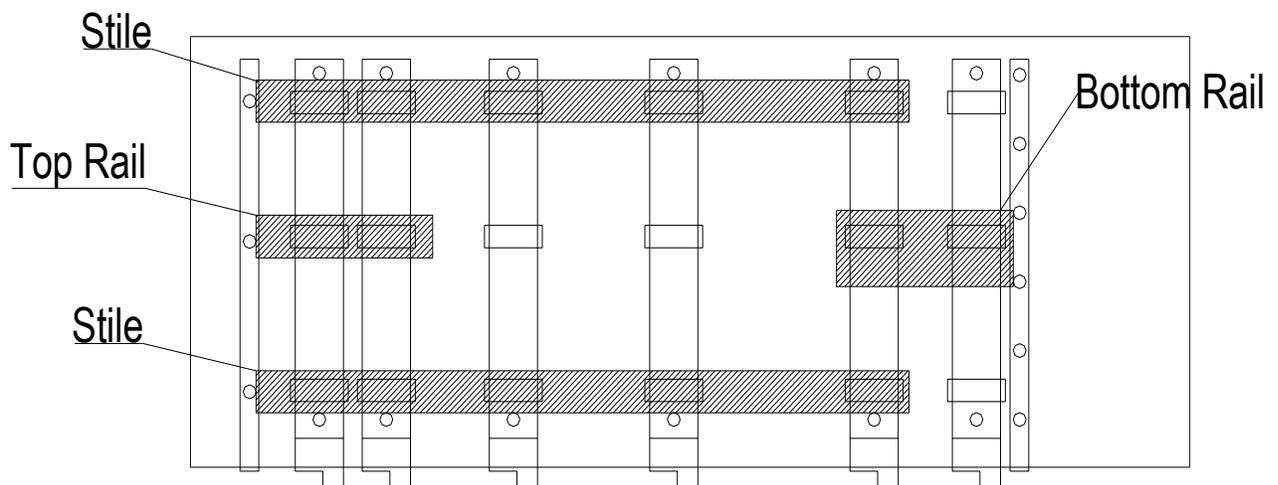
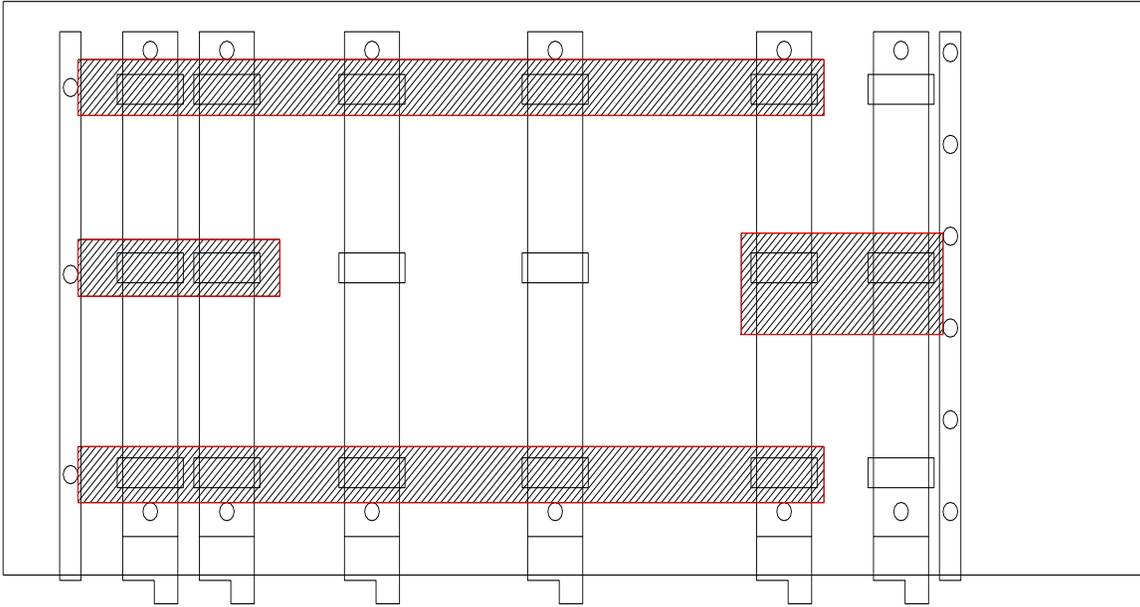


Figure 23. Example of how the components could be loaded onto the machine.

4. The suction is turned on and the reference pins drop.
5. The components are cut to final dimensions using the saw aggregate.



**Figure 24. The cuts needed to cut the stiles and rails to final dimensions.**

6. A 19.5 mm Router bit removes the material from the lock and hinge stiles to make the rabbet for the glass panel.
7. A 19.5 mm Router bit removes the material from the top and bottom rails to make the rabbet for the glass panel (see figures 26 and 27).
8. A 19.5 mm Router bit removes the material from the rail ends and the stile edges to make the rabbet for the half lap joint that joins the rails to the stiles.

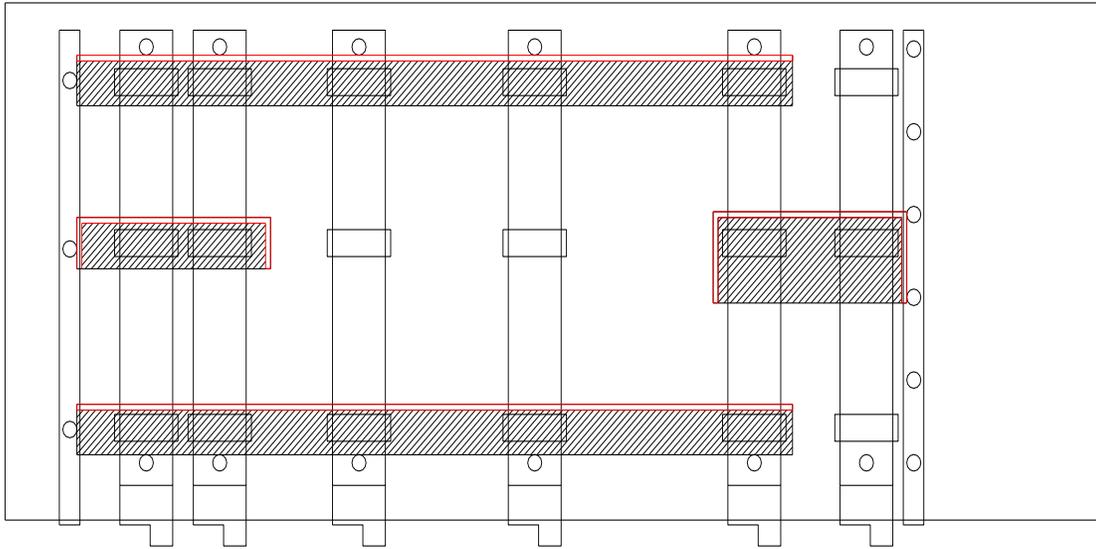


Figure 25. Highlighted surfaces to be machined.

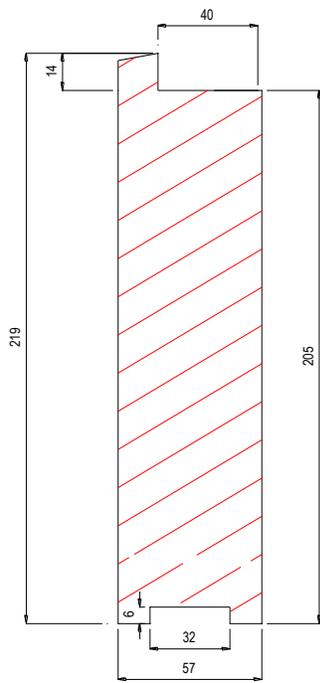


Figure 26. Bottom Rail Dimensions. (Barlow, 2011)

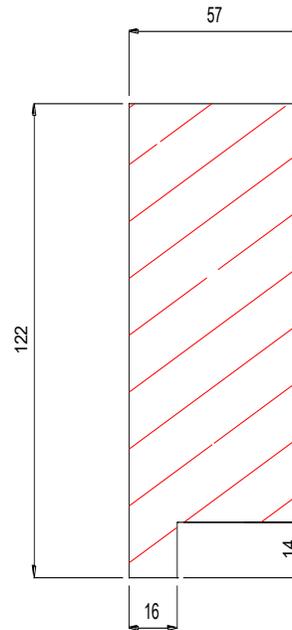
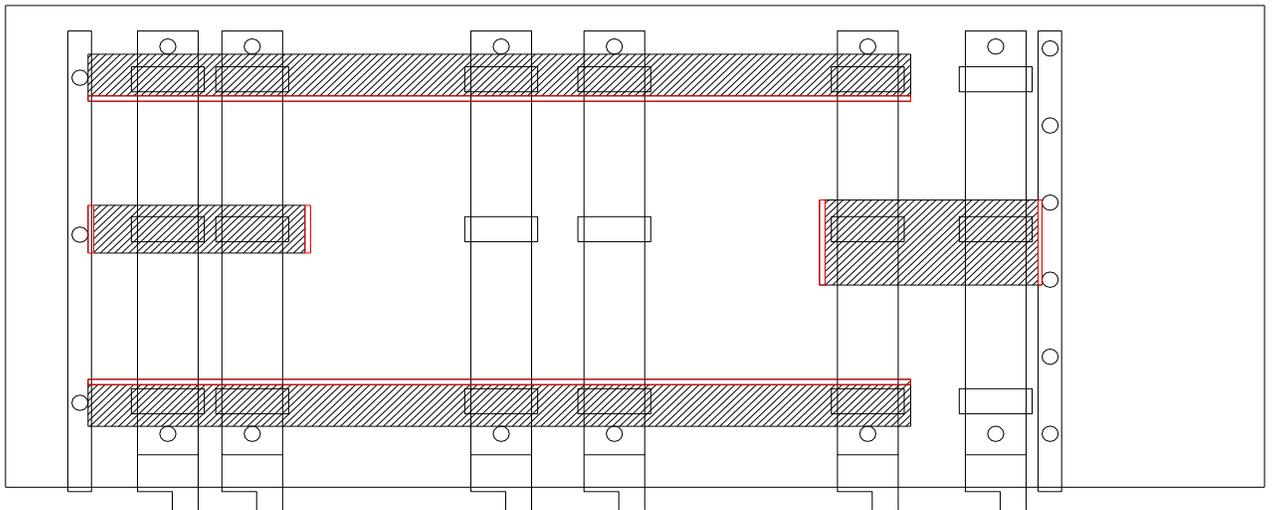
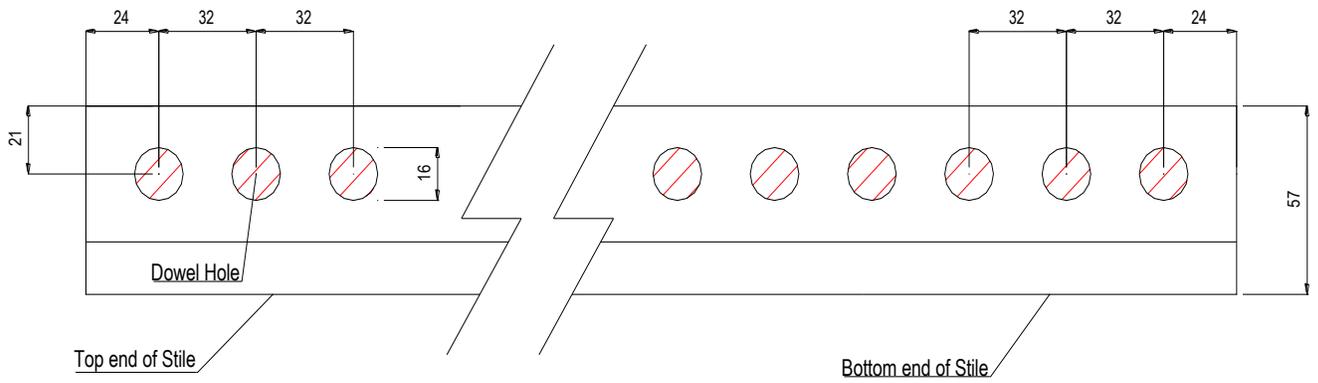


Figure 27. Top Rail Dimensions. (Barlow, 2011)

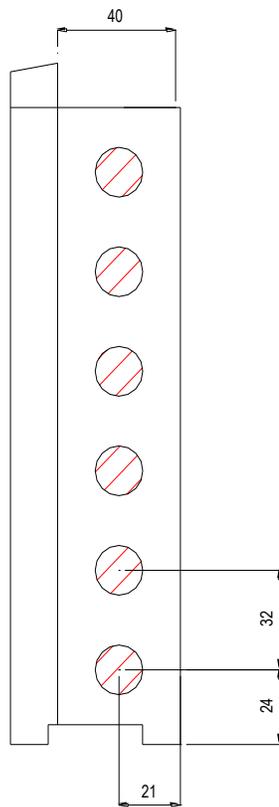
9. Using a 16 mm drill bit and the horizontal drilling aggregate three dowel holes are drilled in each end of the top and bottom rails.
10. Using a 16 mm drill bit and the horizontal drilling aggregate three dowel holes are drilled on the top end of the inside facing side of the lock stile that line up with the three dowel holes that were drilled in the ends of the top rails.
11. Using a 16 mm drill bit and the horizontal drilling aggregate six dowel holes are drilled in the bottom end of the inside facing edge of the stile that line up with the holes that were drilled in the bottom rails. This is done for both the lock stile and the hinge stile



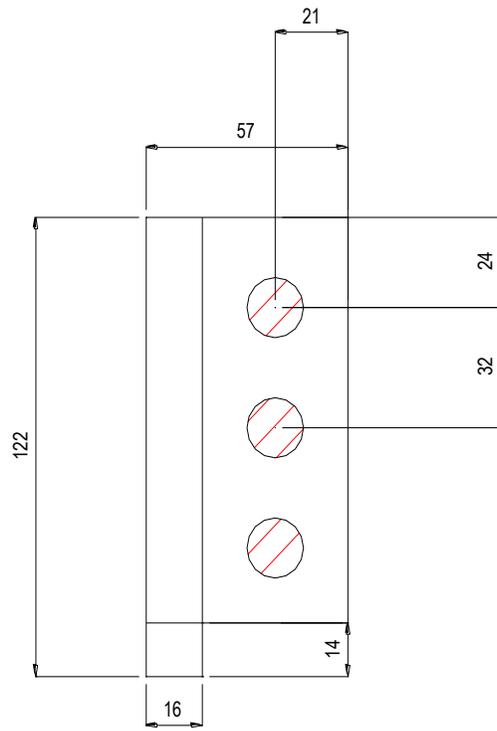
**Figure 28. Faces for dowel hole placement outlined in red.**



**Figure 29. Placement of dowel holes in the lock and hinge stiles.**

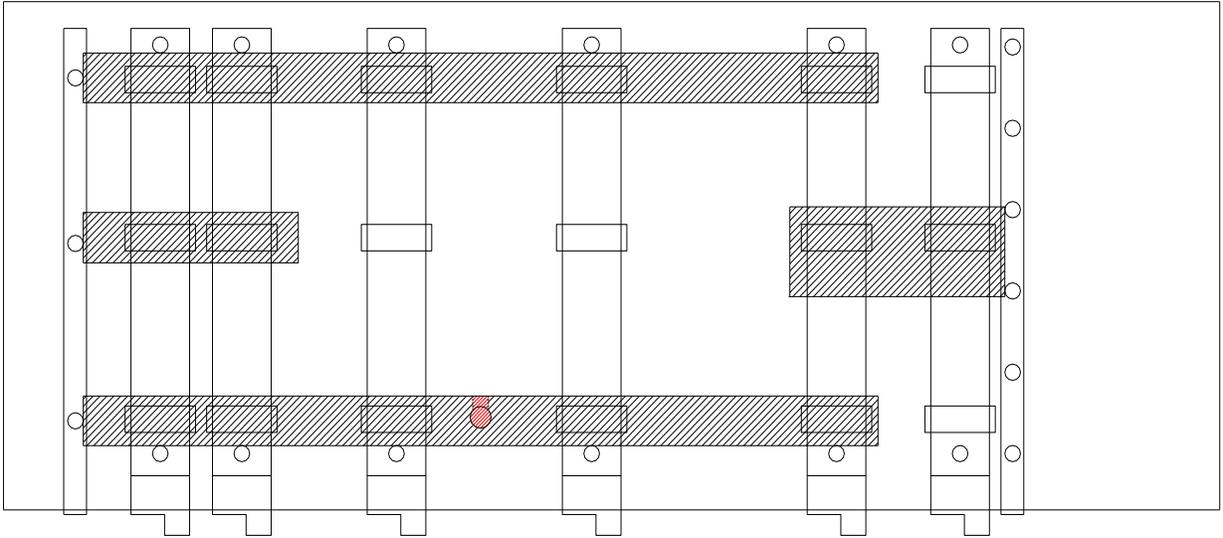


**Figure 30. Placement of dowel holes in the Bottom rail.**

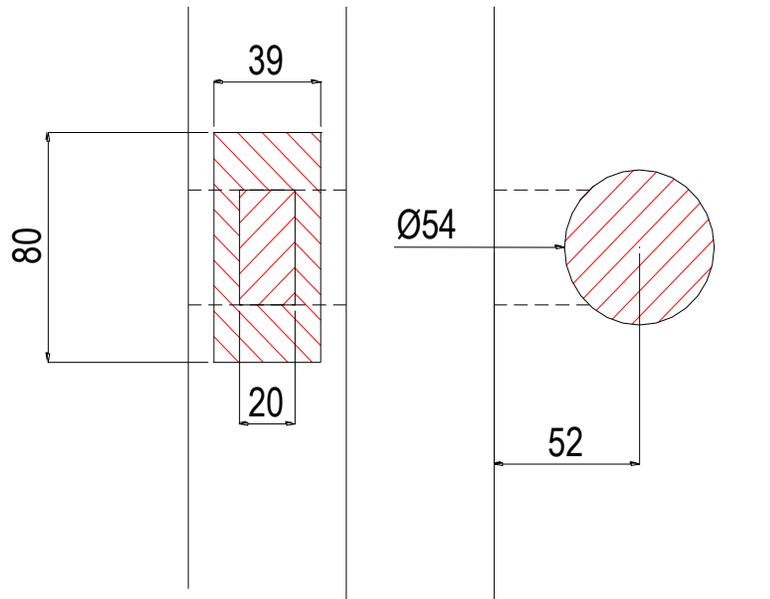


**Figure 31. Placement of Dowel Top and the bottom rail.**

12. A bore hole for the door knob hardware and a pocket for the latch mechanism hardware is routed out of the lock stile using a 19.5 mm router bit. To ensure minimum to no tear out on the bottom surface of the lock stile a slow router speed needs to be used here.



**Figure 32. Bore Hole and latch mechanism pocket in lock stile.**

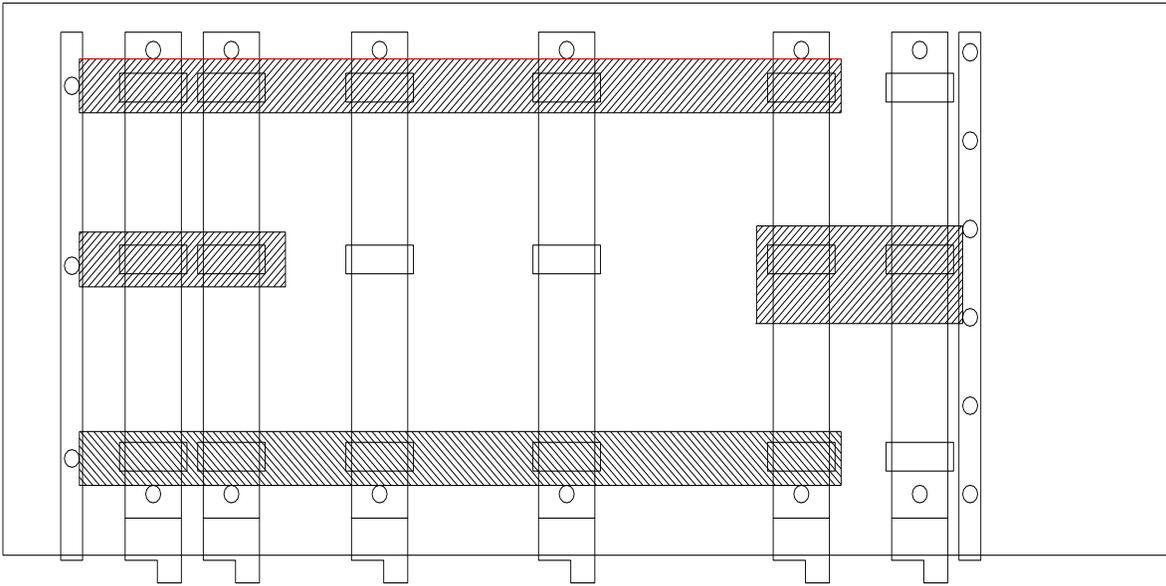


**Figure 33. Bore Hole and Latch pocket dimensions.**

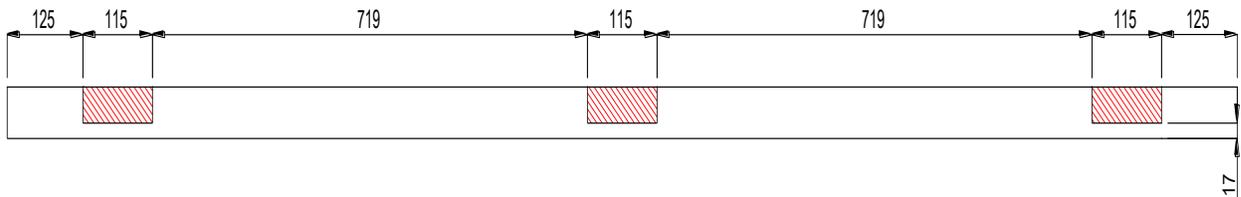
13. A pocket is required on the jamb facing edge of the hinge stile to accommodate the hinge hardware. A 19.5 mm router bit is used to make the pocket.

14. Screw placement holes are then drilled into the pockets to a depth of 3 mm. These holes are used to place the hinge screws for the hinge hardware. They are drilled in a pattern which is

dictated by the type of hinge hardware to be used. The horizontal drilling aggregate is used to drill these holes with a drill bit sized corresponding to the screw size needed for the hinge hardware.



**Figure 34. Surface for hinge pockets and hinge screw holes (outlined in red).**



**Figure 35. Hinge pocket placement on hinge stile.**

### 4.3. Time estimations of machining Door components

**Table 2 Time Estimations for the CNC machining of the Door's Frame (Leung, 2011)**

Process Description	Components machined	Process Repeated	Time (seconds)
<b>Start Machine</b>	load program		20
	position pots	10 seconds per pot	75
<b>Load Components</b>	2 components will be loaded on. 1 lock jamb and 1 hinge jamb	15 seconds per piece x 5 pieces	75
<b>Turn on suction</b>			5
<b>Tool Change 19.5 mm router</b>			10
<b>Machine Rabbit onto ends of jamb</b>	lock jamb ends	1 lock jamb end 10 seconds X ends	20
	hinge jamb ends	1 hinge jamb end 10 seconds x 2 ends	20
<b>Machine hole into lock jamb</b>	lock jamb face		30
<b>Machine pocket into lock jamb</b>	lock jamb edge		20
<b>Machine pockets for hinges into hinge jamb</b>	hinge jamb edge	3 pockets x 20 seconds per pocket	60
<b>Change to drilling aggregate</b>			5
<b>Drill screw holes</b>	hinge jamb edge	4 holes per hinge x 3 hinges per door x 3 seconds per hole	36
<b>Unload components</b>			60
<b>Return home</b>			10
<b>Total time</b>			486

The total Time to machine the door frame components is estimated at 8.1 minutes. These times are estimations taken from an interview with Vincent Leung, the technical facilities supervisor for the Center for Advanced Wood Processing at the University of British Columbia.

Table 3 Time estimations for the CNC machining of the Door's Slab (Leung, 2011)

Process Description	Components machined	Process repeated	Time (seconds)
<b>Start Machine</b>	load program		20
	position pots	10 seconds per pot	50
<b>Load Components</b>	5 components will be loaded onto the machine. 2 stiles and 3 rails.	10 seconds per piece x 5 pieces	50
<b>Turn on suction</b>			5
<b>Tool Change (saw aggregate)</b>			10
<b>Cut components to final dimensions</b>	cross cuts	7 seconds per cross cut x 10 cuts	70
	length cuts	15 seconds per length cut x 10 cuts	150
<b>Tool Change 19.5 mm router</b>			10
<b>Machine profile onto stiles and rails</b>	stile lengths	1 stile length 20 seconds X 2 stiles	40
	rail lengths	1 rail length 10 seconds x 2 rails	20
<b>Machine counter profile on rail ends</b>	rail ends	10 seconds per rail end x 6 rail ends	60
<b>Change to drilling aggregate</b>			5
<b>Drill dowel holes</b>	Stile right faces and rail ends	6 holes on each stile face and 2 holes on each rail end 12 holes in total x 5 seconds per hole	60
<b>Tool Change (3/4 inch router bit)</b>			10
<b>Route hole for door handle hardware</b>	Lock stile	1 hole dimensions specific to hardware	60
<b>Route pocket for door knob</b>	Lock stile	pocket on face of left stile	30
<b>Route pocket for hinge</b>	Hinge stile	20 - 30 seconds per hinge x 3 hinges	90
<b>Tool change to drilling aggregate</b>			5
<b>Drill hinge screw holes</b>	Hinge stile face	4 holes per hinge x 3 hinges per door x 3 seconds per hole	36
<b>Unload components</b>			60
<b>Return home</b>			10
<b>Total time</b>			856

The total time to machine the door slab components is 14.26 minutes. The total time for to machine all components required for the door assembly is 22.36 minutes.

## 5 The specific CNC machine suggested to fill the new CNC tooling requirements

### 5.1. How the suggested machine meets the required tooling requirement

After reviewing several CNC manufacturers and models, and with the recommendations from Karl Frey, the product manager for SCM USA, it was decided that the SCM Record 100 AL TVN Prisma would fulfill all the requirements needed to machine the door frame and door slab components. One of the benefits of this machine is that it comes with a specific kit for machining solid wood doors. This kit includes: "8 reference stops to house the positioning pins, 6 reference stops inside the TVN bar, 14 suction cups (180 mm x 64 mm x 50 mm), 6 suction cups (145 mm x 145 mm x 50 mm), and 6 suction cups (145mm x 55 mm x 55mm)" (see figure 26). (SCM, 2007)

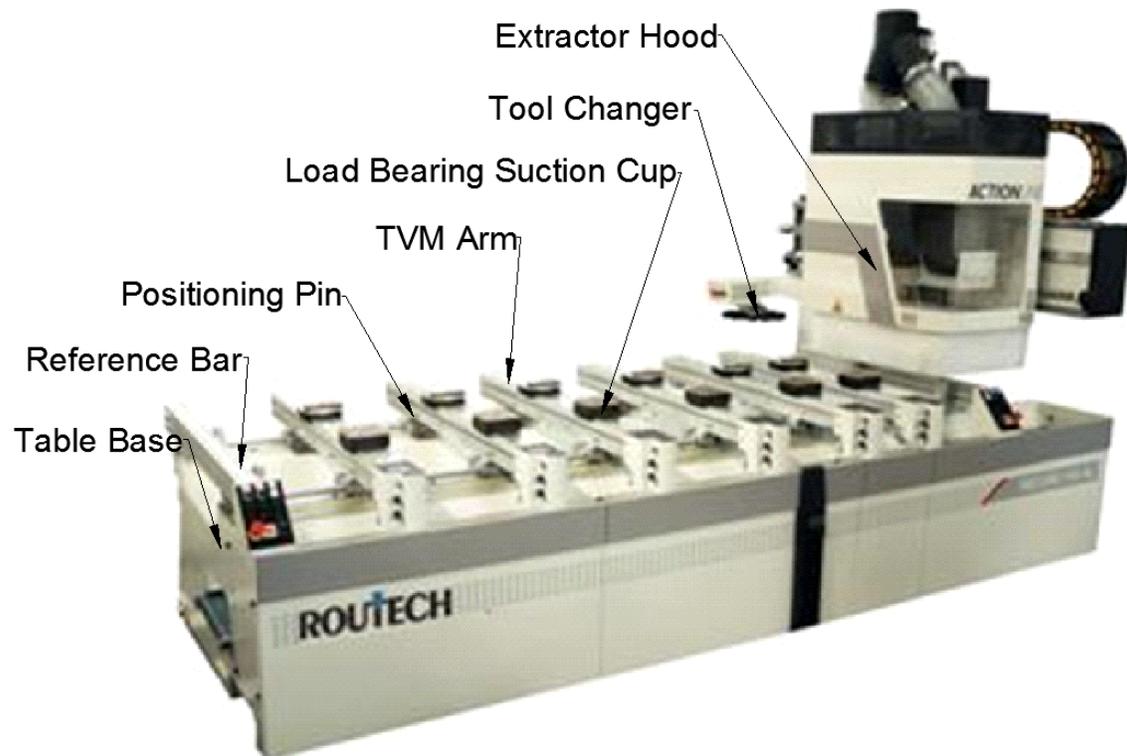


Figure 36. The SCM Record 100 AL (SCM, 2007).

The Record 110 comes equipped with a tubeless vacuum system (TVM) which facilitates the holding down of the piece being manufactured (SCM, 2007). In addition to the TVM suction cups there are mechanical holding devices to ensure that there is no movement of the piece being machined and that all of the machine surfaces are finished clean and without surface defects (see figure 37). The machine has an electro-spindle capable of rotating at 24,000 rpm and a drilling unit configured with 12 vertical and 6 horizontal spindles. (SCMGroup)



**Figure 37. Window held down using mechanical holding devices. (SCMGroup)**



**Figure 38. The tool changer and the spindle. (SCMGroup)**



**Figure 39. Drilling Unit. (SCMGroup)**

This will facilitate the drilling of the hardware screw holes for the hinge hardware. The tool changer is able to support up to 12 tools or aggregates (SCM, 2007) which allow it to be able to hold enough tools to support all the doors machining while having extra space for expansion tools should the company wish to use the machine for additional tasks outside the scope of door manufacturing. Each spindle is equipped with an HSK F 63 chuck. (SCM, 2007) This router is available in 3-axis or 5-axis. Since all machining for the doors are done on the top or side profile 3-axis will suffice for all tooling needs. The SCM Record 100 AL requires 5400 mm by 3800 mm by 2700 mm meters of space including space for the computer and operator, a safety enclosure, and for a safety mat that disable the machine when stepped on. (Hochsmann) This particular machine requires 400 volts / 50 -60 hertz during regular tooling procedures. (Hochsmann) The machine has an estimated purchase price of \$221,000 USD delivered to the North Shore of Vancouver British Columbia and installed in Unison Windows Facility (Frey, 2011).

## **6 Current market trends and economic climate (growth projections, lending rates, tax rates)**

The North American wood products industry is currently in a state of recovery from the US housing market collapse in 2008. Between 2004 and 2009 the market incurred a 7.9% drop in demand

(Webb, 2010). However according to a report by Freedonia the "demand for wood-based windows and doors would increase 7.2% over the next five years, with demand rising from \$7.7 billion in 2009 to \$10.9 billion in 2014" (Webb, 2010). This is nearly a full market recovery predicted. The current floating interest rate is based on the banks prime rate and has no repayment penalties (TD Canada Trust). The banks current prime rate is 3.000 percent (TD Canada Trust). The current tax rate for a small business in British Columbia is 2.5 percent (Ministry of Small Business, Technology and Economic Development , 2011). With the market expecting to make a full recovery coupled with the low tax rates of British Columbia the potential for Unison to be able to sell more of their sold wood doors seems promising.

## **7 Cost / Benefit Analysis Models**

To manufacture the components for the doors frame, and the doors slab using Unison Windows and Doors current process it takes an estimated time of 2.58 hours (Barlow, 2011). A detailed breakdown of how these hours are located can be found in section 4.4 of this paper. To manufacture the components for the doors frame and the doors slab using the CNC router the time estimated is 0.38 hours. The labour rate for the person manufacturing these components is \$60 per hour (Barlow, 2011). The labour cost to manufacture one door is \$155.00 using the old method, while the labour cost to manufacture one door using the proposed CNC based process is \$22.77. This is a total savings of \$132.23 per door. A number of assumptions were necessary in order to conduct the analysis. It was assumed that Unison Windows and Doors would require a small business loan to purchase the CNC machine. This loan would be for \$221,000.00 and would cover the cost, delivery, and installation of the SCM Record 100 AL (Frey, 2011). It was assumed that this loan would be paid back over a period of 20 years and be charged an interest rate of 6%. It was also assumed that Unison Windows and doors would produce 400 doors per year, and that their current market share would be able to fulfill that demand.

### *7.1. Payback period*

This is the time it takes to recover the cost of purchasing the SCM Record 100 AL. The formula used to calculate was: total cost of the investment / annual estimated savings. The initial investment of \$221,000 is required to purchase the CNC machine. The annual savings cash flow is \$30,518 per annum. This gives a payback period of approximately 7.64 years to earn back the initial investment of the CNC machine based solely on the labour savings from manufacturing the doors. A table outlining the cash flows can be found in the appendix.

### *7.2. Net Present Value (NPV)*

The cash inflows used in the NPV calculations were the annual amount of labour savings gained by implementing the CNC machine, the tax savings due to the depreciation of the machine and the final salvage value of the machine. A depreciation of the machines value was calculated using a declining balance of 30% over 20 years. The machine was depreciated down to a final salvage value of \$199.00. A detailed description of the depreciation costs, salvage value and tax savings from depreciation can be found in the appendix. The cash outflows used for the NVP calculation was the loan payments, the cost of maintenance for the machine, and the cost of electricity required to run the machine. The loan payments are made monthly over a period of 20 years with an interest rate of 6%. The cost of maintenance for the machine was estimated at 1 percent of the machines total cost and then grew at a rate of 5% per year. The NPV was calculated over a 20 year period. To calculate net present value each year's revenue (inflows – outflows) is discounted back to its present value (PV) and then they are summed. The following formula is used

**Equation 1. Net Present Value Equation (Zohrabyan)**

$$NPV = \sum_{t=0}^n \frac{(\text{Benefits} - \text{Costs})_t}{(1 + r)^t}$$

where:

**r = discount rate**

**t = year**

**n = analytic horizon (in years)**

An Excel function was used to calculate the NPV and the value returned was \$318,486.37. This means that an investment in purchasing this CNC machine will generate a savings of \$318,486.37 over a twenty year time period using a rate of return of 6%. The positive NPV value indicates that investing in this machine will add a value of \$318,486.37 dollars to the company over a 20 year period if all cash inflows and outflows remain constant. This positive value indicates that this investment is worthwhile.

**7.3. CNC Replacement advantages**

There are a number of advantages Unison Windows and Doors will gain by upgrading their door manufacturing process to utilize CNC based routing. CNC routing will not only add efficiency to their manufacturing process but will save time and in turn labour costs. Instead of measuring a piece to be cut, machining the profile of the piece and then checking the accuracy of the cut, each piece will be cut to exact specifications every time without any measuring and checking required. This reduces the amount of labour time for manufacturing the door slab components by 680.82%, and generates a labour savings of \$132.63 per door. The tool change time between manufacturing will also be decreased as the CNC machine requires no operator set up, calibration or control to facilitate tool changes. CNC based routing will also minimize the amount of material movement within the facility. The current door manufacturing process

requires the doors components to be machined on 4 different work stations (the table saw, the thickness planer, the shaper, and the dowel drilling station). This requires the worker to not only move from station to station, but to set up each machine prior to use and to clean the machine area after use. Moving to a CNC based process will only require the initial program to be loaded, and the components to be loaded and unloaded from the machine. The chips are removed using a vacuum tube located in the extractor hood, and any wood waste that is generated during machining is collected via a conveyor belt that runs under the TVM arms through the machine's table (SCM, 2007). Another advantage of the CNC process is the lack of quality control checks required. Previously it was required to take careful measurements and to manufacture jigs in order to drill the dowel holes, route the hinge hardware pockets, and drill the bore hole and corresponding pocket for the latch mechanism. With the new proposed process all that is needed is to ensure each component is placed correctly using the location pins of the CNC machine, and these features will be machined to the exact specifications of the program. This will also eliminate the dry fit assembly stage of the manufacturing process, and will greatly reduce the amount of re-machining time needed for components that have been manufactured incorrectly.

#### *7.4. CNC Replacement disadvantages*

The purchase of the Record 110 AL TVN Prisma is a huge investment, and as such inherits the risks that occur when investing a large monetary sum. Before doors can begin to be manufactured there is a lot of set up time to ensure that the machine is installed and operating correctly. Programs to manufacture the doors components must be written and tested by a competent CadCAM programmer and significant training must be given to manufacturing personnel on how to effectively load and operate the machine. The process of machining the door components and fitting them together accurately prior to the CNC process required a

highly skilled woodworking craftsman, while the new process does not. Removing the craft from the woodworking process can be viewed as undesirable to certain people. There may be times during Unisons business where jobs without doors or with very few doors are moving through the shop. During these times the CNC machine could potentially remain unutilized.

## **8 Conclusions**

An investment in a SCM Record 100 AL TVN Prisma CNC Router and a change in Unison Windows and Doors current process to automate the production of solid wood door components would be desirable at this time. By greatly reducing their labour costs the new CNC machine would save Unison Windows \$30,689 annually. In addition to the savings this investment will also free up 884 hours of shop time per year that could be used to complete other projects. The models used in this paper were calculated using a production rate of 400 doors a year. This is roughly 2 doors per day. The time estimated to manufacture the components for 1 door was 22 minutes. This means that the SCM Record 100 AK TVN Prisma is able to manufacture the components for 4 doors per hour, which is 32 doors per day. With the forecasting of the solid wood door industry to grow 7.2% over the next five years this will enable Unison Windows and Doors to easily meet the new markets demand. The current process for manufacturing the French Swing door is labour intensive. This is due to the care needed to align the bore hole with the latch mechanism pocket, accurately place the dowel holes, and accurately place the pockets for the hinge hardware. By being able to program the placement of these features reduces a lot of the time wasted measuring for the placement of the cuts and aligning of the tools. The need to manufacture and re-manufacture custom jigs has been eliminated. The machine will also greatly reduce the amount of time currently necessary to remanufacture components that have been made inaccurately. Unison Windows and Doors take pride in producing many different customized projects. The CNC routing process may not make sense for the machining of all components. However, by automating the production of many standardized components

much of the shop employee's time is freed to focus on manufacturing the specialized components necessary for the type of projects Unison Windows and Doors customers' desire. Finally, with a positive NPV of \$318,486.37, and a payback period of 7.64 years the investment in the CNC router makes economic sense.

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## Appendix

Table 4 Cash Flows for economic analysis

CF Tax included	Year										
	0	1	2	3	4	5	6	7	8	9	
Total	0	30689	30564	30433	30295	30150	29998	29839	29671	29495	
<b>Outflows</b>											
Fixed Costs (loan payment)		19268	19268	19268	19268	19268	19268	19268	19268	19268	19268
Machine maintenance		2500	2625	2756	2894	3039	3191	3350	3518	3694	
Electricity charges	0	596	596	596	596	596	596	596	596	596	596
<b>Inflows</b>											
Savings	0	53053	53053	53053	53053	53053	53053	53053	53053	53053	53053
Tax savings from depreciation											
Machine Salvage											
cumulative net returns	0	30689	61253	91686	121981	152131	182130	211969	241640	271135	
	10	11	12	13	14	15	16	17	18	19	20
Total	29311	29117	28913	28699	28475	28239	27992	27732	27459	27173	27166
<b>Outflows</b>											
Fixed Costs (loan payment)	19268	19268	19268	19268	19268	19268	19268	19268	19268	19268	19268
Machine maintenance	3878	4072	4276	4490	4714	4950	5197	5457	5730	6017	6317
Electricity charges	596	596	596	596	596	596	596	596	596	596	596
<b>Inflows</b>											
Savings	53053	53053	53053	53053	53053	53053	53053	53053	53053	53053	53053
Tax savings from depreciation											118
Machine Salvage											176
cumulative net returns	300446	329563	358476								

**Table 5 Machine Depreciation Calculations**

<b>Machine (@ 30% Declining Balance)</b>					
<b>Year</b>	<b>Initial Book Value</b>	<b>Depreciation Rate</b>	<b>Depreciation Expense</b>	<b>Accumulated Depreciation</b>	<b>Year End Book Value</b>
1	221000	30%	66300	66300	154700
2	154700	30%	46410	112710	108290
3	108290	30%	32487	145197	75803
4	75803	30%	22740.9	167937.9	53062.1
5	53062.1	30%	15918.63	183856.53	37143.47
6	37143.47	30%	11143.041	194999.571	26000.429
7	26000.429	30%	7800.1287	202799.6997	18200.3003
8	18200.3003	30%	5460.09009	208259.7898	12740.21021
9	12740.21021	30%	3822.063063	212081.8529	8918.147147
10	8918.147147	30%	2675.444144	214757.297	6242.703003
11	6242.703003	30%	1872.810901	216630.1079	4369.892102
12	4369.892102	30%	1310.967631	217941.0755	3058.924471
13	3058.924471	30%	917.6773414	218858.7529	2141.24713
14	2141.24713	30%	642.374139	219501.127	1498.872991
15	1498.872991	30%	449.6618973	219950.7889	1049.211094
16	1049.211094	30%	314.7633281	220265.5522	734.4477656
17	734.4477656	30%	220.3343297	220485.8866	514.1134359
18	514.1134359	30%	154.2340308	220640.1206	359.8794051
19	359.8794051	30%	107.9638215	220748.0844	251.9155836
20	251.9155836	30%	75.57467508	220823.6591	176.3409085
21	176.3409085	130%	229.2431811	221052.9023	-52.90227256