# How Technology Could Increase Production Capacity

# for a Small Artisan Woodworking Shop

by

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A Research Paper

Submitted in Partial Fulfillment of the
Requirements for the
Master of Science Degree in
Technology Management

Approved for Completion of 2 Semester Credits
INMGT-735 Field Problem

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June, 2007

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**Title:** ***How Technology Could Increase Production Capacity for a Small Artisan Woodworking Shop***

**Graduate Degree/ Major: MS Technology Management**

**Research Adviser: Jerry L. Roiter, Ph.D.**

**Number of Pages: 41**

**Style Manual Used: American Psychological Association, 5th edition**

## ABSTRACT

Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), and Computer Numeric Control (CNC) routers have revolutionized the commercial woodworking industry. Over the past decade, these technologies have become viable for small custom woodshops which specialize in low-volume, high quality custom work. Understanding how these technologies are reshaping the woodworking and woodcarving industries and how they can be utilized to maximize productivity and profit is a necessity for those who wish to remain competitive.

This study will explore how these technologies are being utilized currently throughout the woodworking and woodcarving industries and will demonstrate how these Technologies could add value by optimizing the production process of a small woodworking shop.

# ACKNOWLEDGEMENTS

I would like to thank Dr. Jerry Roiter for his insight and guidance throughout this process.

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# Chapter I: Introduction

*Statement of Problem*

The use of technology to gain a competitive advantage in business was once limited to large companies producing very large quantities of homogeneous products. However, with the increase in the affordability and power of the personal computer over the last decade, software designers are now creating products with the small quantity, highly customizable producers in mind. The result has been products that are scalable, easy to use, highly customizable, and, most importantly, affordable. The availability and accuracy of this technology has reshaped virtually every industry and product we encounter, including woodworking. As the nature of their industry is redefined, small one or two person woodworking shops are being forced to adapt to stay competitive.

*Purpose of the Study*

The purpose of this study is to explore the way in which technology is changing the woodworking industry and to demonstrate how utilizing Computer Aided Design (CAD), Computer Aided Design (CAM), and Computer Numerical Controlled (CNC) routers would add value for a small woodworking shop which specializes in custom carved wood furniture. For the purposes of anonymity, the name of the woodworking shop will not be disclosed and will heretofore be identified as ABC for the purposes of this paper.

*Company Background*

ABC is an owner operated woodworking shop which specializes in creating traditional Orthodox carved furniture pieces. The shop, consisting of the owner and 1 assistant, has been in business for 9 years and serves a nationwide clientele. The products ABC produces vary in size and complexity and can take anywhere from 200 hours to 3500 hours to complete. All shop operations are currently done manually; these include bidding and design, fabrication, carving, assembly, and finishing of the product. The shop is currently only utilizing technology in the form of a website for advertising and bookkeeping software.

ABC is currently operating at capacity given the current size of its shop, staff, and production methods. Faced with the need to add capacity without expanding in size, ABC is seeking to expand its capacity by refining its production process through the targeted use of technology.

*Definition of Terms*

*Computer Aided Design, abbr. CAD.* "The use of computer programs and systems to design detailed two- or three-dimensional models of physical objects, such as mechanical parts, buildings, and molecules. (The American Heritage® Dictionary of the English Language, Fourth Edition. http://dictionary.reference.com/browse/CAM)

*Computer Aided Manufacturing, abbr. CAM.* "The processes of using specialized computers to control, monitor, and adjust tools and machinery in manufacturing." (The American Heritage® Dictionary of the English Language, Fourth Edition. http://dictionary.reference.com/browse/CAM)

*Computer Numeric Control, abbr. CNC.* Manufacturing machines that are operated using "G-Code" created by a CAM software program.

*Critical-Path.* "The necessary path or sequence from start to finish, determining the time needed for completion; the longest most time-consuming path in a network." (*The* American Heritage® Dictionary of the English Language, Fourth Edition. http://dictionary.reference.com/browse/critical path)

*Methodology*

This study will be conducted in the following manner. It will identify new technology and how it is being utilized in the field of woodworking and woodcarving. The study will further describe ABCs current production process, and identify opportunities where incorporating CAD/CAM or CNC could add capacity by refining the production process.

# Chapter II: Literature Review

In an era of global competition and specialization, the woodworking industry has been forced to evolve technologically to remain competitive. "As they go head-to-head with the world's low cost labor regions, American manufacturers are looking for the most effective ways to bring new efficiency and flexibility to the shop floor" (Summers, 2003, p. 89). This search for efficiency and flexibility led the industry to begin adapting technologies from other industries such as Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) software and Computer Numeric Control (CNC) routers. "CAD/CAM software originated in metalworking and precision manufacturing, but over the past five or 10 years, it has made a dent in the woodworking industry. Today, woodworkers can choose from an extensive range of products developed especially for them (Bury, 2006, p. 179). These new woodworking specific software programs have been reshaping the competitive nature of the industry and have become a vital part of a company's success. To put it succinctly: "Computers are becoming more of a necessity than a luxury for today's woodworkers, especially when it comes to designing and machining a project in a timely manner and at a competitive price." (New Software, 1997, p. 53)

## CAD

The ability to bring new products from idea to production quickly and accurately is an essential part of the woodworking industry. J. Harold Kirby described the importance of product development on the industry this way:

> Let's not forget what we do. We are manufacturers of furniture and wood products and our competitive position in the marketplace is dependent on our ability to get product to the market faster, with a better value, at the least cost to our company. But the old ways and old thinking will lead you to the inevitable position of non-competitiveness (1997, p. 45).

In the search to increase their competitiveness, many in the industry have found "CAD provides the most productive environment in which to manage and modify engineering documents" (Wilson, 1993, p. 100). CAD offers the user the ability to better manage its new product development through increased design origination and communication capabilities.

## Design Origination

CAD offers several ways to originate the initial two-dimensional (2D) or three-dimensional (3D) "electronic equivalent of a blueprint, in formats such as IGES, DXF, or DWG" (Bury, 2006, p179). This can be done by (a) creating a new file, (b) modify an existing file, and (c) scanning existing designs and prototypes.

*Creating a new file*

As manufacturers provide CAD programs specifically for the woodworker, the efficiency of creating new files has increased. "Most of the new generation of CAD/CAM programs start with libraries of standard parts, or templates, and allow users to modify them to fit their customers needs or to create whole new parts and products" (Bury, 2006, p. 181). The use of these templates can translate into substantial saving in design time. Walt Moore, a cabinet maker who began using KCDw, a cabinet specific

CAD program, stated, "...once he learned how to use it, the software turned eight hours of work into 1-1/2 hours"(Sampson, 2005, p. 35).

*Modifying an existing file*

Another method of creating the CAD file is to modify an existing file, since all previous "designs can be saved and used again."(O Rourke, 1993, p. 58). This allows designers to edit only the necessary elements, rather than completely recreate the design "which speeds product development and lowers costs" (O Rourke, 1993).

The ability to modify existing files applies not only to files created in a CAD program. "Developers for illustration and publishing software quickly adopted DXF for its ability to import and export" Cad files, "making it a de facto standard." (O Rourke, 1993) This flexibility allows consumers to bring their ideas, generated "in the best program for a task, and export the work back to the CAD file." (O Rourke, 1993) This step again eliminates the need to totally recreate the CAD drawing when such a file exists. Not only is this faster than redrawing the object, it reduces the opportunity for input error that is inherent in any redesign.

*Scanning Existing Designs & Prototypes*

In addition to drawing and modifying files, scanning pictures, documents, and prototypes are other options CAD offers for design origination. For those who have manually drafted blueprints, CAD conversion and Raster Drafting are two "scanner-based technologies" that allow the designs to be converted for use in CAD. This is a great benefit to companies who have a large design portfolio, as they are able to build a digital library of past designs for future use and modification.

Scanning is not just limited to drawings and designs; companies can use 3-D digital scanning to create CAD files from existing prototypes. The scanner creates data output files in the form of surface-mesh and cloud-points. These files can be converted into DWG and DXF format for CAD use. The scans offer a level of complexity that would be almost impossible to generate by drawing. "I am not sure how long it would have taken using CAD software, or whether it could have been done at all because of the sculpture's complex and detailed surfaces," said Jordan Peppin when asked about a digital scan his company did of a fish sculpture. However, using the scanner, "Peppin estimates it took about four hours to create the distal fish model." (Moltenbrey, 2001, p. 50)

## Communication

Once the initial CAD file is originated, it serves as the backbone for the rest of the project. From this file, the information can be communicated to all necessary parties to proceed with the editing and revision of the design. CAD provides an unparalleled ability to communicate through the use of 3-D modeling and the ability to transmit the file via e-mail.

### *3-D Modeling*

The ability to create and view a three dimensional (3D) model using CAD is an incredibly powerful tool for saving time and improving accuracy in the design process. This capability is helpful with communicating with both the design principals, as well as those tasked with production.

*Design Principals.* One way creating a 3-D model of the project can reduce time is that it allows all involved in the process to view the project in its proposed completion, complete with photo realistic color, texture, and shadowing. This can be especially helpful in creating ownership and bridging any terminology or expectation gaps among those involved in the design. One architect put it this way, "Gaining their trust and cooperation often hinges on delivering a first-rate presentation, in language the can understand." (Hill, 1999, p. 20) The renderings can be edited easily to show how different options will look when applied to the design. These options help bring a sense of confidence to the decision process and ensure all involved they know what they are getting.

A poignant example of how 3-D CAD modeling can facilitate design and create buy-in is found in Julie Hills account of a school renovation project in Sommerville Massachusetts, in her article <u>For Architect's Audience, Seeing (in 3 D) is Believing:</u>

> "For the residents of Somerville, the last point of contention on the new school building was the size and color of its exterior bricks. DataCAD made it easy to change the tiling of the exterior walls and show four different options. The final planning meeting was held on the site, allowing residents to examine the four images of the new school in the open air and vote for their favorite. "The end result was a building with no surprises, since the community had taken part in the design process."" (Hill, 1999, p. 20 )

*Production.* Another benefit of 3-D modeling is the ability to ensure that the design will be ready for the production floor and assembly. Because the program "lets the user assemble, view, and revise dimensionally on a computer screen," it eliminates the need to build prototypes to test the design. (Kirby, 1997, p. 45) Manufacturers in the furniture industry have found that 3-D programs have cut "segments of product development time by as much as 50 percent," while eliminating "virtually all engineering errors." (Kirby, 1997, p. 45) Because the production plans are generated directly from the computer, it helps create "engineering integrity." As J.Harold Kriby describes in his article Utilizing 3-D CAD Systems:

> "Incomplete route sheets create interruptions and parts that don't fit. Let's eliminate this untold cost and create engineering integrity. Integrity creates credibility and credibility is what our machine operators want from the engineering department. Does the route sheet have integrity? When I cut it by this dimension, will the credibility be good when we assemble it?" (1997, p. 49)

*Transmitting the file via E-mail*

The ability to transmit the design file via e-mail is another area where CAD adds value in the communication of a design through its ability to distribute the design quickly and accurately to all parties involved. During the design, editing, and revision of the product, the files can be sent instantly around the globe. Rather than printing many copies of the plans and mailing or faxing them, the original file can be sent, ensuring that all parties are looking at the same design and dimensions. Edits can be made directly to the original and quickly submitted for approval. In his article Save Money On Drawings, Dave Wilson cites a study claiming that revisions done using CAD could be accomplished in 1/8$^{th}$ of the time it took to make a manual revision(1993, p. 100). When combined with the elimination of printing copies of each revision and the time saved waiting for revisions to arrive in the mail, the benefit of being able to transmit the file via e-mail can be considerable.

The use of CAD to decrease design time, while increasing the accuracy and integrity of the design, can lead to considerable time savings in the design process. The finalized design in CAD file format can be seamlessly incorporated into the production process to maximize its benefit through the use of Computer Aided Machining (CAM) and Computer Numeric Controlled (CNC) routers.

## CAM/CNC

Just as CAD technology has driven efficiencies in the design, editing, and modeling of woodworking and woodcarving, the use of Computer Aided Machining (CAM) and Computer Numeric Controlled routers have changed how woodworkers and woodcarvers create their products. These technologies have increased both the speed and accuracy of the woodworker and allow companies to increase capacity and competitiveness without increasing their size. "CNC machines are almost considered "standard," even in shops with five or fewer employee." (Bury, 2006, p. 179)

Once a design is created in CAD, it can then be passed on to the CAM program to convert the files into useable data for the woodshop. This includes "parts lists, bills of material, cost estimates, and even invoices." Additionally, "CAM software also produces electronic code that the CNC router needs to do its work," including "toolpaths, tool selection, tool speeds, and drill depths." (Bury, 2006, p. 180) Once programmed, the CNC machine will proceed to route out the designs that were programmed.

As the use of CNC machines gained popularity in the woodworking industry, software companies were quick to begin offering specialized programs to suit the needs of the industry. Today, a shop can choose from dozens of woodworking specific CAD/CAM programs designed to maximize the productivity of the user. The main area of woodworking specialization has been in the cabinet making industry; however, architectural woodworking and woodcarving are also available. "Some software includes options lie advanced engraving, which enables you to produce the same quality of hand carved craftsmanship using CNC Machines ( Summers, 2003, p. 91). These technologies have paid great dividends to the user.

Architectural Woodworking

. In his article CNC Machines offer speed, accuracy in woodworking jobs, Ray Culin cites the benefit of using a CNC router for his custom millwork company.

> "In 4,000 hours, Culin/collela produced miles of curved molding and other custom millwork using a CNC wood router driven by a personal computer. This was about half the time it would have taken to make all these products using traditional methods. The router improved the work accuracy by a factor of 10.... Creating large curved wood pieces by hand requires making a trammel and physically swinging an arc to calculate curve radii. Instead, Culin/Collela created shop drawings in its CAD System. CAD data was transferred to the router's CAM system to create

toolpaths for the router.... Without CNC equipment, Culin/Collela could not have even bid on this contract, much less won it." (1998, p.46)

## Wood Carving

The impact on the woodcarving industry has been similarly remarkable. Both high volume architectural woodcarving producers and small artisan woodcarvers are finding CAD/CAM and CNC technologies the way of the future. In 1989, Thermwood, a CNC manufacturer, introduced the idea of using a CNC machine to reproduce wood carvings. However, carving with a CNC router had to wait for even more powerful computers. It wasn't until 1995 that Thermwood revolutionized the carving world when it announced, ita "routers were capable of three-dimensional wood carving," and that it had a "new programming system that could be operated by almost anyone." ( Wood Carving, 1995, p. 145)

*High Volume Architectural Wood carving Producers*

This shift in the industry was initially limited to the large producer due to the high cost of the CNC machines needed to complete the carving. Doug Nemeth, corporate sales manager at Mastercam/CNC, described the initial constraints like this: "A CNC machine as an expensive piece of capital equipment, and acquiring the first one turns a craftsman's woodworking shop into a serious business, where the first concern is not necessarily "how good is the tool?" but what is the rate of return?" (Bury, 2006, p. 187) With early CNC machines running in the hundreds of thousands of dollars, the risk was great, but for those companies who could afford the machines, the investment paid off.

Once such company is Enkeboll Designs, a company which specializes in architectural elements and wood carvings. "Using a row of specialized CNC machining centers," Enkeboll has built a company that provides "intricate carvings in large lots, with no sacrifice to quality" to customers around the world. The company offers over 4000 products and continues to grow in light of low-cost foreign competition. "We thrive by offering a better, more consistent product, by being more flexible and able to do exactly what the customers ask for, and by being more productive through the targeted use of technology and human capital" (Ehle,2006)

The face of the CNC user began to change in the mid nineteen-nineties, as the increase in computing power allowed companies to develop smaller, cheaper CNC machines able to provide the same capabilities on a smaller scale. Steven Hard, vice president of marketing for Planit Solutions, describes the changing market like this in an article for June, 2006 issue of Wood & Wood Products Journal: "The profile of the typical CAM user has changed in the past 18 months. Two markets are emerging: the entry-level market that CNC manufacturers have built, and the high end users of the [more sophisticated] CNC machines." Michael Grohs, director of sales for Virtual Systems, another CAM software developer, agrees, citing, "even quite small shops using sophisticated CAM software for their CNC machines – a concept that only a few years ago was restricted to the largest shops. It's opening up a new market sector." (Bury, 2006, p. 187)

*Artisan Wood Carvers*

This new market sector, and the increase of powerful software and CNC technologies directed toward the small wood shop, coupled with other technologies such as 3-D scanning, has allowed artisan woodcarvers to effectively utilize technology to increase their productivity. Kevin Edgar, an artist, turned to CNC when looking for "the optimum technology to increase the production rate" of his 3-D intarsia portraits. "I have a passion for the art form and for working in wood, it was very important to me that I select a method of design and manufacturing that allowed me to create the quality of handmade artwork at production quantities." He settled on CNC because it "offered speed, accurate reproducibility and of course, automated operation." Using a scanner and a CNC router with a CAM program, he can bring his ideas to life quickly and accurately. "One nice thing about Mastercam is that I can go from photograph to a completely machined piece in two to three hours, so I have new pieces on the market almost instantly," he says, discussing the impact CNC has had on his business in an article for the January 2002 issue of Wood & Wood Products Journal (CAM Joins Art, p. 90).

Scott Clinton, a wood-carver who specializes in realistic looking fish, turned to CNC milling and 3-D modeling to reduce the time it took to create each sculpture. By scanning a 3-D model of his sculpture, he was able to convert the file into a pattern for rough cutting on a CNC machine. He cites "time savings" as the "biggest advantage to using digital technology. I can now produce far more fish a day, which gives me more time to hand paint and apply finishes on each sculpture." Clinton summed up his feelings about using technology to increase his production this way. "There are some old-school carvers out there who can't bring themselves to move from a chisel and knife to power tools, let alone a computer-generated 'carving.' They may not like to admit it, but computer technology has opened a whole new world for artist without affecting the quality of the art." (Moltenbrey, 2001, p. 50)

# Chapter III: Methodology

ABC is looking for ways in which technology can be used to increase capacity without increasing the size if its shop. The fist step of this process is describing ABC's current production process and then identifying where technology can improve the way it brings products to market.

*Study Elements*

This study will consist of the following elements:

1. Current production process of ABC.
2. Opportunity for implementing technology
3. Proposed Production-Process Utilizing Technology

*Data Collection*

The data used in this study is historical, provided by ABC based on internal record keeping. This data is used to assign a percentage value to each of the 5 elements of the production process. These percentages are based on the average time ABC currently requires to complete each element over the course of a project. (Table 1)

Table 1

Production Process Percentage Data Based on Historical Data

| Production Process Element | Percentage of total Project |
|---|---|
| Bidding and Design | 15 |
| Fabrication | 13 |
| Carving | 60 |
| Assembly | 10 |
| Finish and Installation | 2 |

# Chapter IV: Results

## CURRENT PRODUCTION PROCESS OF ABC

This section will cover the production process currently used by ABC. It will include an overview of the 5 elements of the production process, a flow chart of the process, an in-depth description of the activities that take place in each element, and a chart showing the current critical path in the production process.

### 5 elements of the production process

ABC has developed a production process that is currently broken into 5 elements. These elements encapsulate all the steps that are preformed by ABC throughout the course of a project. These 5 elements are:

1. Bidding and Design
2. Fabrication
3. Carving

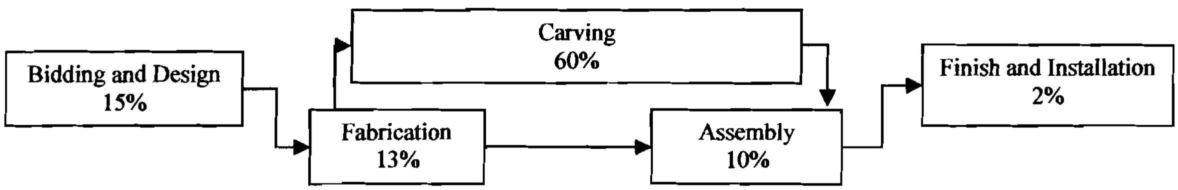
4. Assembly

5. Finishing and Installation

Production Process Flow Chart

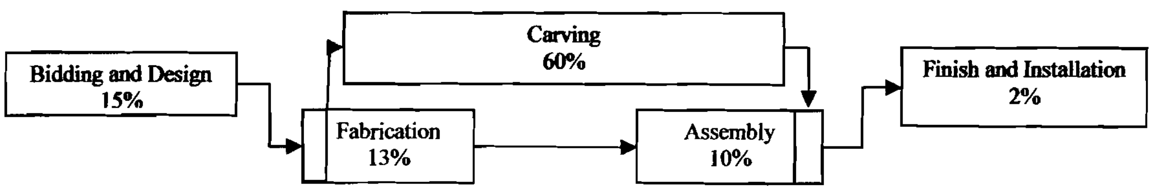
Based on historical data, ABC has been able to assign a percentage of the total project to each of the 5 elements. A flow-cart of ABCs current production-process with assigned percentages is shown in Figure 1. The critical-path flow-chart of ABCs production-process is shown in figure 2.

Figure 1




Flow-Chart of ABCs Current Production-Process Not to Scale

Figure 2




Critical-Path Flow-Chart of ABCs Current Production-Process Not to Scale

Detailed description of the 5 elements

This section will provide a detailed description of the steps included in each of the 5 elements of the production process: bidding and design, fabrication, carving, assembly, and finish and installation.

*Bidding & Design*

The bidding and design element consists of the point of contact, initial design, communication and revision, bidding, and final proposal. This element accounts for 15% of the total work hours for a project. A breakdown of the percentage based on historical data is found in Table 2.

Table 2

Bidding & Design Process Historical Data

| Bidding & Design | % of Bidding and Design | Percentage of Total Project |
|---|---|---|
| Point of Contact | 3% | .5% |
| Initial Design | 53% | 8 % |
| Communication and Revision | 27% | 4% |
| Bidding | 10% | 1.5% |
| Final Proposal | 7% | 1% |

*Point of Contact.* Because all of the projects ABC works on are custom, they begin with a point of contact. The point of contact is typically an email or telephone call inquiring about a specific project the client has in mind. The type of project, material, size, timeline, and price range will usually be discussed in this process.

*Initial Design.* Although each piece is custom, the carving style ABC specializes in consists of roughly 9 furniture pieces, and the majority of its work is some variation of one of these pieces. This helps in the generation of the initial idea from which to begin the design process, as ABC has a portfolio of work which can be emailed to the client.

This allows the client to view pictures of previous work and develop a strong base line from which both ABC and the client can begin to modify the design.

*Communication and Revision.* Because the designs are hand drawn, the revision process can be a time consuming one. Once an initial design is created, it must be copied and sent via mail to the client, a step that can take up to a week for the shipping alone. Any revisions require a redrawing of the complete design, which is both labor intensive and is an opportunity for unnecessary error. Once the revision is completed, it must be copied and sent via mail again. This process is repeated until the design is completed. Additionally, since the drawings are two-dimensional line drawings, it can be hard for clients to visualize how the changes will actually look as a finished product.

*Bidding.* As the design nears completion, the bid is produced. The bid is based on the estimated cost of materials, labor, square feet of carving, and any additional factors that need to be accounted for. The estimates are completed by measuring and figuring out a price for each component of the piece. This can be a time consuming process with some projects having hundreds of unique components. The bid is produced as thoroughly and accurately as possible.

*Final Proposal.* Once the design is finalized, the finished design along with a final bid is sent via mail to the client for approval. Due to the ecclesiastical nature of the carvings, this approval is usually some form of board appointed to oversee the project. Due to its line-drawing format, the drawing cannot accurately represent the finished designs color, depth, shadowing, and how it will look when complete. The proposal will be accepted, rejected, or returned for modification.

*Fabrication Process*

Once the design is approved and the contract is signed, ABC begins its fabrication process. This element consists of creating a final cut list, purchasing materials, and fabricating the individual parts that will make up the project. This element accounts for 13% of the total work hours of a project. A break-down of the percentage based on historical data is found in Table 3.

Table 3

Fabrication Process Historical Data

| Fabrication Process | Percentage of Fabrication Process | Percentage of Total Project |
|---|---|---|
| Final Cut-List | 8% | 1% |
| Purchasing Materials | 8% | 1% |
| Fabrication Of Carved Panels | 15% | 2% |
| Non-Carved Fabrication | 69% | 9% |

*Final Cut-List.* The final-cut list is created by checking the earlier cut list created for the estimate, to see where they changed through the revision process. Revising the cut list accurately is vital to ensure the parts are built to the specification of the final design, allowing for an efficient and accurate assembly. Mistakes made at this stage can lead to costly re-fabrication and delays in project completion; therefore, all dimensions and quantities are double checked two ensure they match the design.

*Purchasing Materials.* A materials list is generated from final cut list and used to order the necessary wood and any other items needed for completion. The list is calculated by taking the final cut-list and converting the totals to board feet so it can be ordered. For the wood order, an additional 20% is added to the total to account for variations in color, grain, and clarity. The materials typically take from 2 to 3 weeks to arrive, depending on the specifics of the order.

*Fabrication.* Upon delivery of the materials, the fabrication process begins. The first step in this process is to fabricate all the portions of the project that will be carved. Once prepared, these parts are sent to the carver, and the carving process can begin while the rest of the project is fabricated.

All fabrication is done in the shop and consists of manually jointing, planing, sawing, drilling, routing, and sanding the parts. Fabrication of arches and other complex elements are very time consuming and require either the manufacture of jigs or the use of large trammels to achieve desired radii. Because arches are a dominant design theme in much of the work ABC does, this is a major portion of the fabrication process.

*Carving*

The carving element begins when the fabrication of the carved portions are complete. It includes scaling and transferring the design, removal of negative spaces, and carving the design. This element accounts for 60% of the total work hours for a project. A breakdown of the percentage based on historical data is found in Table 4.

Table 4

Carving Process Historical Data

| Carving | Percentage of Carving Element | Percentage of Total Project |
|---|---|---|
| Scaling & Transfer of Design | 3% | 2% |
| Removal of Negative Spaces | 9% | 5.5 % |
| Carving | 88% | 52.5% |

*Scaling and Transfer of Design.* Once panels are fabricated, the carving process can begin. This process begins by scaling the carving designs by hand from 1/8$^{th}$ scale to full size drawings and transferred onto the panels. This is done by manually tracing the design onto the panels.

*Removal of Negative Spaces.* ABC specializes in pierced carving; this means all portions of a panel that are not included in the carving are removed, leaving only the carved design on the panel. Each of these negative spaces is drilled and then scroll sawed to create the pierces effect of the design. This process takes on average 4 minutes per hole with the number of holes per panel ranging from 50 to over 300, depending on the size and design of the panel.

*Carving.* Once the negative spaces are removed, the carver begins carving the actual design. This process takes on average 20 hours per square foot of carving. All carving is done by hand using carving chisels and other hand tools. Upon completion of the carved panel, it is sanded and then becomes ready for assembly.

*Assembly*

Assembly consists of two parts, non-carved and final assembly. This element accounts for 10% of the total work hours for a project. A breakdown of the percentage based on historical data is found in Table 5.

Table 5

Assembly Process Historical Data

| Assembly | Percentage of Assembly Element | Percentage of Total Project |
| --- | --- | --- |
| Non-Carved Assembly | 80% | 8% |
| Final Assembly | 20% | 2% |

*Non-Carved Assembly.* Non-carved assembly begins upon completion of the fabrication of the project. All completed parts are assembled as per the design, and the project will await the completion of all carved panels to complete the final assembly. The assembly is done using conventional woodworking techniques and methods. Success in the assembly process is driven by the accuracy of the fabrication and design. When parts are produced improperly, or when the design doesn't accurately allow for parts to be fitted as produced, the process can be a long and frustrating one. Small inaccuracies can easily compound over an entire assembly to create the need for prefabrication or alteration of the design.

*Final Assembly.* Final assembly is contingent on the completion and installation of all carved panels. Upon completion the project is ready for finishing and installation.

*Finish and Installation*

Finish and Installation is the final element of ABC's production process and accounts for 2% of the total work hours for a project. This element includes finishing the project and installation when necessary. A breakdown of the percentage based on historical data is found in Table 6.

Table 6

Finish and Installation Process Historical Data

| Finish & Installation | Percentage of Finish & Installation | Percentage of Total Project |
|---|---|---|
| Finishing | 50% | 1% |
| Installation | 50% | 1% |

*Finishing.* Once assembled, projects enter their final phase, finish and installation. The project will be taken to a finishing shop, where the desired finish is applied. This is typically a clear lacquer, but the type of finish is dependent on the specifics of each piece.

*Installation.* Once the finish has cured, the piece will be either installed or shipped to the customer. Installation is done by ABC with the goal of no on-site modifications.

# OPPORTUNITY FOR IMPLEMENTING TECHNOLOGY

## How Technology Could Impact ABCs Production Process

There is an opportunity for technology to be implemented in the bidding and design, fabrication, carving, and assembly elements of ABC's production process. In this section, we will discuss how technology could be used to improve these elements.

### *Bidding and Design*

Implementing CAD could have a tremendous impact on ABC's design and bidding process. The ability to scan prior designs into the program, reduce design and revision labor, speed communication, increase visualization, and more accurately estimate costs, are all ways CAD can benefit ABC Woodcarving.

*Scan Prior Drawings.* ABC could quickly build a library of digital files by "converting their manual drawings to CAD-based drawings through the use of CAD conversion or Raster drafting." (Wilson 1993, p. 100) This would allow ABC to convert the dozens of past designs and commonly used elements into CAD without having to recreate them.

*Reduce Design and Revision Labor.* Once these drawings are scanned into CAD, they can act as a starting point for future idea generation. As ABC gains proficiency in the use of CAD, it can expect to see its initial design time decrease dramatically without sacrificing accuracy. Time savings in initial design have been quoted at over 80 percent (Sampson, 2005, p. 34 and up to 85 percent on revision of CAD versus manual drawings.(Wilson,1993, p. 100)

*Speed Communication.* In addition to labor savings in the drawing of the design and revisions, the entire design and bidding process can be shortened through the ability to email the files across the country, rather than relying on mailing a hard copy of the design. This ability alone could drastically reduce the design and bidding process, allowing for multiple iterations of the design to be available as fast as they can be drawn. This can mean saving weeks, and possibly months on a small projects when working with committees that meet infrequently and have many questions.

*Visualization.* The ability to render the project in 3-D ensures allows both the client and ABC to view both the design and revisions for aesthetic and structural approval. ABC can be sure the design can be produced as drawn by eliminating "engineering errors" (Kirby, 1997, p.45) that would require later modification. Additionally, clients can be confident of an outcome with "no surprises," since they were able to see how their questions and suggestions would change the end product in a "photo-realistic" rendering the design. (Hill, 1999, p. 20)

*Estimate Costs.* Cut-lists can be generated easily with each revision using the CAM software, allowing ABC to more accurately estimate its labor and materials costs. This will allow ABC bid more competitively by eliminating the need to increase the bid to cover estimating inaccuracies.

*Fabrication*

CAD, CAM, and CNC routers could benefit every aspect of ABCs fabrication process. In each task, final cut sheet, materials purchasing, and fabrication, ABC would see increased accuracy, while reducing its efforts.

*Final Cut-Sheet.* The final cut-sheet, created during the bidding process using CAM software, is ready to be used for fabrication. Because the cut -sheet is generated directly from the drawings, it ensures complete accuracy, eliminating the possibility for dimensional or data entry errors. Automating this process not only saves labor hours in generating the list, but it helps to create "engineering integrity" (Kirby1997, p.49 ), giving the fabricator confidence in the accuracy of the dimensions.

*Purchasing Materials.* Because the final cut-sheet will be completely accurate, the materials list will also be more accurate. Wood can be ordered precut, based on the cut-sheet to minimize waste, resulting in a more accurate materials list. This will save time and money in addition to the valuable shop space not needed to store unnecessary material for the project.

*Fabrication*

Because of this confidence in the cut list, ABC could begin to subcontract the fabrication of projects. This would allow ABC to focus on the area of the project where it adds the most value, the design and carving, and let companies who specialize in the accurate production of wood parts to add value to the fabrication. An example of a possible subcontractor would be either a cabinet maker or a furniture manufacturer with a production shop and a CNC router. Using CAM software to convert the CAD drawings into G-code that controls the CNC router allows for the parts to be fabricated automatically from the original drawings. Complex design elements such as arches and ovals can be cut quickly and accurately using the CNC router, reducing fabrication time by up to 50% while increasing "the accuracy by a factor of 10" (Culin,1998, p.46 )

*Carving*

The impact of technology on the carving process, while initially small, could eventually change the way ABC produces its carvings. Immediate impacts on the carving element would come in the area of scaling and transferring of the design and removal of negative spaces. The impact on the actual carving portion, while not immediate, could be the greatest benefit of all.

*Scaling and Transfer of Design.* CAD would save time in this step of the carving element by eliminating the need to manually rescale the carved design to full size. CAD allows the user to make scaling changes with the click of a mouse, rather than the hours it currently takes.

*Removal of Negative Spaces.* The drilling and removal of negative spaces could be done using a CNC router, which could greatly reduce the time needed to complete these tasks.

*Carving.* The immediate benefit to the carving process of implementing CAD would be the reduction in the time spent by ABC on design and fabrication. This would allow ABC to focus more time directly on the area that it adds the most value, carving. This ability to focus ABC's energy to this process would lead to improved productivity through repetition and optimize its carving technique and process.

The largest potential impact, however, would be revolutionizing the way ABC actually carves each piece, taking a design created using CAD and produce the carvings using a CNC router. By exporting the CAD file into a 3-D CAM program that specializes in carving such as V-Carve or ARTCAM pro, ABC can begin to automate its carving process. This would further reduce the time spent on carving by allowing the CNC router to completely rough out the carved design, leaving only the final carving for ABC. By eliminating the vast majority of the material surrounding the design, using a CNC router would allow ABC to focus only on the finished product. For a small woodshop like ABC, the ability to focus their limited manpower on the final carvings would greatly increase the overall productivity, while spending "more time on the finishing touches." (Moltenby 2001, p. 50)

*Assembly*

Technology would continue to benefit ABC through a more accurate and efficient assembly process. Because the parts could be cut using a CNC router to the exact design specifications, the assembly should proceed smoothly and accurately. With alignment tools such as dowels, splines, mortise and tenons cut by the CNC router during the fabrication process, the parts can be assembled to create the final result with limited additional effort by ABC.

Additionally, because the CAD files can include sections and assembly details, the assembly could also be subcontracted. With all the information the assembler would need available on the CAD file, ABC could be confident the end product would meet the design.

## Proposed Production-Process Utilizing Technology

*Initial Time Savings*

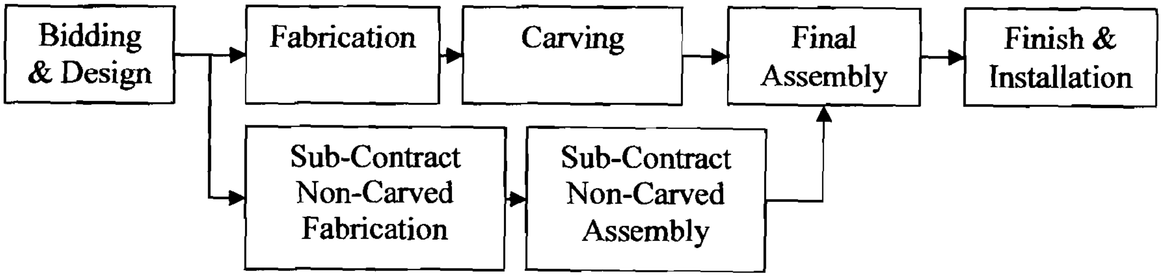
If ABC began utilizing a CAD software program, it would be able to restructure its production process immediately. Implementing CAD would allow ABC to sub-contract the non-carved fabrication and the non-carved assembly portions of the production process, freeing up 17% of the total project that could be focused on the critical path. (See Figures 3 & 4) This is based only on implementing CAD in the design process and assuming no immediate savings to any of the historical percentages previously assigned to the production elements. (See Table 7)

Table 7

Proposed Production Process

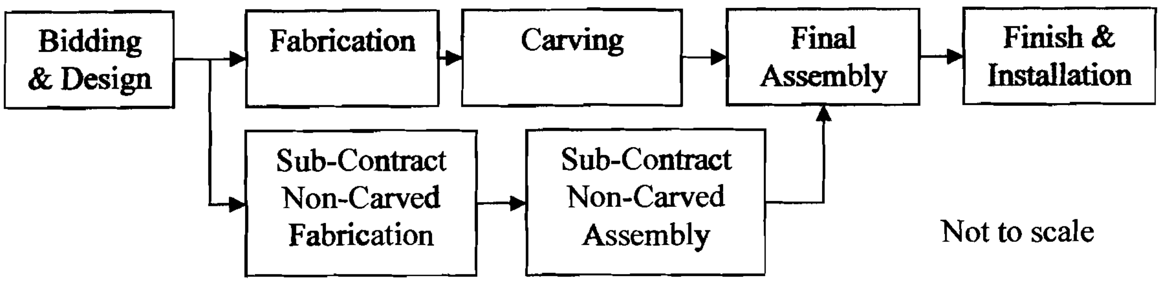
| Proposed Production Process | Critical Path | Non-Critical Path |
|---|---|---|
| Bidding & Design | 15% | |
| Fabrication | 4% | |
| Non-Carved Fabrication | | 9% |
| Carving | 60% | |
| Non-Carved Assembly | | 8% |
| Final Assembly | 2% | |
| Finish & Installation | 2% | |

Figure 3




Proposed Production-Process Utilizing Technology Not to Scale

Figure 4




Proposed Production-Process Utilizing Technology Critical-Path

*Potential Time Savings*

Additional savings could be gained as ABC becomes more efficient in using CAD for design. As shown by Dave Wilson in his article Saving Money on Drawings, the time savings in switching from manual design to CAD can be up to 80%.

Finding subcontractors who use a CNC router would create additional time savings, as they would be able to complete the fabrication and assembly in less time than ABC is currently taking. This savings could be up to 50%, as shown by Ray Culin in his article CNC Machines Offer Speed, Accuracy in Woodworking Jobs.

Finally, if ABC can begin to harness CAD/CAM and CNC for the carving element, it could vastly increase its productivity, as this is where the majority of its efforts are currently spent.

## Chapter V: Discussion

### Conclusion

In an effort to increase its productivity without increasing its size, ABC is looking for ways technology could be implemented to improve its production process. CAD, CAM, and CNC routers are technologies that are being used effectively throughout the woodworking industry to increase the efficiency of new product development. Utilizing these products effectively can help create a competitive advantage in today's marketplace.

ABC can gain immediate benefits from implementing CAD. The software would allow ABC to more accurately design its products. This would allow ABC to begin to subcontract portions of the fabrication and assembly process, reducing its labor by 17%. This would allow ABC to spend its energy on only critical path elements of the production process that can only be accomplished by ABC. This will allow ABC to increase its capacity by completing projects in a shorter time period.

In addition to the initial savings, ABC can expect to gain future time savings as it becomes more efficient in its use of CAD and find ways to incorporate CAM and CNC routers into the production process.

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