INNOVATIVE USE OF COMPUTER NUMERICALLY CONTROLLED WOOD PROCESSING TECHNOLOGY FOR THE FLEXIBLE MANUFACTURE OF FURNITURE TOWARDS AN OPTIMAL BATCH SIZE OF ONE.

By

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Abstract

While the adoption of CNC technologies in Australia has been rapid by World standards, the successful integration of machines and systems into the Australian solid timber furniture factory has been harder to achieve. This dissertation aims to assess elements of the furniture manufacturing process using CNC equipment to identify best practice and lean manufacturing solutions. Small batch sizes suitable for flexible manufacturing are the goal of every manufacturer; however variations in part design, order quantities, delivery deadlines and setup times make actual batch size calculations difficult to define.

This study will assess methods that could be used to reduce batch sizes; in particular the viability of combining all of the components for one piece of furniture into a single CNC program. A number of examples will be presented and the advantages and disadvantages to small batch sizes evaluated and discussed. CNC machinery, cutting tools, tool holding devices and emerging technology will be assessed for performance and suitability for lean manufacturing and small batch sizes. Practical methods to improve production efficiency by organizing workflow and re-thinking how components are processed will be demonstrated.

This work concludes that there is no commercial gain in combining all of the parts of a piece of furniture in the one CNC program. It (rather) finds that utilizing appropriate cutting tools and smart processes will bring about gains in productivity that is currently unrealized. It finds that the capability exists within the current performance of CAD and CNC processing to reduce setup and machining times further than are presently achieved in the Australian furniture industry. It finds that training does not adequately provide industry with the skilled workers required and it finds that industry does not always purchase machinery suitable for small batch sizes or for processing the variety of materials used in Australian furniture manufacture.

The major findings were that for the processing of kitchen cabinets; a nested manufacturing solution delivered the most benefits for small batch-size
production. Rail machines are recommended for small batch sizes of furniture using predominantly solid wood. The smallest batch size is not always the best batch size. It was determined that in the case of a small batch processing multiple parts in the same cycle with a jig in solid wood; there is no saving in time. The use of high-performance tools is highly recommended in order to take advantage of lessened runout, quick-change tool systems and stacked tooling. Applying the tool in a “power feed” direction may not always be the most ideal in terms of breakout; tool life and power consumption. More efficient ways of processing parts are available to the manufacturer and this was demonstrated by combining common parts into one processing cycle. The layout of the furniture factory has a direct effect on the material flow and productivity. The range of issues identified in Mo et al. (2001) can be improved with training. Skilled workers are required to investigate the production sequence and put in place best practice for CNC production.
DECLARATION

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any University; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person where due reference is not made in the text.

………………………… Philip Neil Ashley

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Executive Summary

The Australian furniture industry has access to the World’s most advanced CNC machinery and equipment; however, the industry often fails to take full advantage of the potential of CNC, resulting in less than optimum levels of production where the unit production cost is lowest and therefore the profit margin is the highest. Trade practices are widely used and production practices used by high-volume manufacturers are unsuitable for the small to medium enterprises that characterize the Australian furniture industry. The industry must adopt a more studied approach to the way it manufactures components.

Retailers now demand a high-quality product at the lowest possible price, delivered within a demanding time-frame. To achieve this, furniture manufacturers need to shorten production times while maintaining a quality product. Manufacturers must also be flexible in terms of the design of the furniture and the quantities produced. Furniture orders from a batch of one need to be produced economically.

Furniture manufacturers currently manufacture in batch sizes based on perceived or historical demand patterns. Some manufacturers base their production on the Kanban system but stock is still built up to the perceived demand. For instance, a manufacturer would keep ten coffee tables (in parts) in stock and when the parts fell to a pre-determined number (say 2) an order would be generated to produce more parts. The minimum order would be set to the time that would elapse until the stock could be filled again.

With CNC however, it should be possible to manufacture on-demand and to be able to accommodate fluctuations in demand. This assumes that the factory is not backlogged with orders. In fact, if only the parts required for the immediate order were in production, it is likely that no work is left standing, no bottlenecks will occur and one furniture item could be produced.

The actual manufacture (make-time) of any furniture item by CNC machining has a number of basic elements. These are programming; set-up; loading and
unloading; machining time and clean-up. Programming time is the time it takes to create a CAD drawing of the part and turn it into a machine-readable file. Set-up involves the input of the program to the machine controller; the installation and set-up of cutting tools and tool data and the fitting of any jigs or other devices required to hold the work. Loading and unloading involves the feeding of the work to the machine and clean up involves removing jigs and waste for the next job. Reducing the time it takes to perform any or all of these elements will produce manufacturing gains and lead to leaner production.

The objective of this work is to examine all areas of the furniture manufacturing process where CNC machinery is used to produce components prior to assembly; to identify where the process can be improved and lead-times reduced, leading to the possibility of smaller batch sizes. Ideally the best batch size is one but this may not always be the best result.

The objectives of the research were:

- To establish the current state of furniture manufacturing in Australia.
- To investigate the processing requirements for manufacturing complex furniture products on CNC equipment.
- To analyse the issues in current CNC manufacturing process that inhibit manufacturing solid wood furniture components on CNC machinery with batch size one ideology.
- To evaluate current processing systems inclusive of part nesting for effectiveness.
- To perform a case study to establish World best practice in small batch manufacturing.
- To define batch size one.
- To investigate the conditions necessary for batch size of one to be effective inclusive of process planning, machine setup, tooling and related CNC machining sub-systems.
• To explore the factors affecting optimum cutting conditions of cutting tools on CNC timber cutting machinery.

• To explore further means of more effectively processing furniture components.

The methodology for the work was to:

• Research the development of CNC manufacturing in Australia.

• Gather commentary from and observe a wide cross-section of industry within Australia and overseas to establish best practice.

• Establish current skills gaps relevant to CNC manufacturing.

• Establish product suitable for batch size of one manufacturing.

• Assess small batch size methodology.

• Re-design the processing of a sample CNC furniture component to demonstrate lean production principles.

The programming of furniture components can be achieved manually at the machine or by the many CAD programs available to the manufacturer. CAD is considered a luxury purchase by many manufacturers and is used in an ad-hoc fashion. The training provided by the software supplier is often delivered in a limited time-frame and during this time the manufacturer is usually still producing. The resulting benefits are often minimal and the software is blamed for not producing an effective outcome. Employees trained in the use of software often move to another company offering higher wages. Some companies have several software programs that end up in an office drawer without ever having reached its full potential. Whatever the program used, after the drawing has been created and converted to a machine file, it must be loaded onto the machine computer.

The set-up of the machine is potentially the part of the manufacturing process that is the most time consuming and the area that should be looked at to reduce manufacturing costs. The process starts with the purchase of a CNC machine and recommendations are provided in this document.
A modern CNC machine can store many cutting tools provided one is purchased that meets the current and expected future demands of the company. With insufficient tools available in the tool change magazine for the range of work performed, the work will slow. It is better to have too many tool holding slots than too few. The (cutting) tool data will be set in the computer when any new tool is added to the magazine so the more tools the machine can hold; the less data setting will need to be done. Tools should be carefully selected for maximum versatility. A number of basic tools will be required to rough-cut and finish cut straight edges. A number of profile tools will also need to be available depending on the number of edge profiles the company produces. A tool “system” capable of accepting a range of profiles while not affecting the tool data (tools will have a common constant radial and axial dimension) will eliminate most of the changes needed between different components. The use of stacked tools where several profiles are grouped on the one cutting tool is becoming more common and should be considered when making tooling purchases. Recommendations for CNC tooling is provided in this document.

Set up also involves the setting of any jigs to hold the furniture piece(s). Large and difficult-to-handle jigs should be avoided as their installation adds time to the manufacturing process. The smaller the batch, the less time the jig should take to install and un-install from the machine. It is hardly economical to take 15 minutes to install a jig when only one piece of furniture is needed. Generally, the longer the set-up time; the larger the batch must be to offset the set-up cost. The use of a jig may be required for small and narrow furniture parts but machining these in multiple using the supplied hold-down devices is a possibility that should be explored and an example is provided in this document.

The loading and unloading of parts for a CNC machining cycle is non-productive and should be reduced as much as possible. Loading all of the parts onto a single jig may seem a good idea but takes skill in placing the parts that need to be placed accurately onto a rubber seal. The miss-placement of parts could result in that part not being machined properly and a new one required. Replacing one part from the many run in the one cycle on the one jig is
problematical because a whole new set of parts will need to be run to get the part that we need. The more parts on a jig the more difficult it will be to obtain a good seal on all of the parts. This document will assess in detail the advantages and disadvantages of running components in single or multiple machining cycles; using jigs and using the holding devices provided by the machine supplier.

The machining time may be able to be improved, however the processing time of ten furniture components will generally be ten times that of one component. The "processing time" is the total time from entering the program and making any machine set-ups such as adding jigs and tooling; to the completion of the job inclusive of the removal of any jigs and clean-up. Small gains may be made by grouping parts together but this saving could be offset with difficulties created by the holding of the grouped components. A modern CNC machine will have a (non-cutting) positioning speed of up to 100m/min therefore the time between cutting is very short. Long set-up times reduce the daily machining time of a CNC machine.

Clean up time is the time it takes to remove any jigs and waste from the machining area and be ready for the next job. If the job can be done with minimal use of specialist jigs and the minimum creation of waste parts; a more productive CNC machine will result. This document explores the machining of CNC parts where the waste is managed during the machining cycle.
1. Introduction

1.1 The Issue

The current state of the Australian Furniture Industry is reasonably well-developed in the area of CNC nested based manufacturing for flat panel manufacture. For the solid wood working sector, the state of the industry is less developed. Mo et al. (2001) cites “Unsatisfactory use of computer systems and equipment” as a major point of concern for the furniture manufacturing industry in Australia. Mo also states "There is no obvious difference between manufacturing using a CNC machine and that using traditional wood-machining technology."

The document identifies a range of issues of importance to the Australian furniture industry focusing on production efficiency. The document is a stage 1 report of the Production Efficiency Improvement Program of the Furnishing Industry Action Agenda. In the executive summary six manufacturing weaknesses were identified. One of these, item three was "unsatisfactory use of computer systems and equipment." Furniture manufacturing in Australia is traditionally a high volume production system with a high-mix of products and parts. To remain competitive it must change to low volume high-mix production. Mo et al. (2001) states "In an ideal situation, the goal for CNC technology is to make one complete set of furniture components ready to assemble and eliminate batches of components on the shop floor." This manufacturing solution is referred to in the report as "Batch Size One" and by inference is a low volume system.

Trade literature reveals that in Germany a major CNC machine manufacturer has been using the term “Batch size one" for many years. It is used in conjunction with "Just in time" and this term has been used in Australia since the late 1980's. It is not a new concept. In Germany the term "Batch size one" is used to describe a process of automation whereby a product is selected resulting in several high-cost machines selecting and processing a small number of parts made usually from manufactured board. The meaning of batch size one in the European context does not readily apply to the very small batch sizes required by
Australian manufacturer's using solid wood as the resource material and low-cost CNC equipment.

The definition of batch size is “The evaluation of how many products should be produced for an inventory analysis.” Batch size one as described by Mo (2001) is interpreted to be a manufacturing process where a number of parts common to one piece of furniture are gathered by a worker and placed onto a CNC machine table. The parts are then processed in the one production cycle.

Batch size one is practiced in the flat panel sector of the industry (kitchens and bathrooms) as nested based manufacturing (NBM) and this technology is discussed in this document. Advice from machinery suppliers and evidence regarding TAFE (training) enrolments indicate that over 90% of the furniture industry uses flat panel product leaving 10% of the industry to benefit from batch size of one using solid timber. The aim of the study was to examine the feasibility of cost-effectively manufacturing one complete set of solid wood furniture components as a batch size of one. It is unlikely that only one manufacturing variable would be considered in the study. One variable will be the purchase and storage costs of the stock machined and this will increase as batch sizes increase. Conversely, production and more importantly, set-up costs will increase as batch sizes decrease.

1.2 Objectives and research Questions

Modern CNC technologies have automated machining processes significantly. However, industry is still using batch processing methods with large quantities which are inflexible to meet current market demand. This thesis investigates the barriers for industry to achieve batch size of one and suggests new manufacturing methods to achieve the most flexible manufacturing systems for solid timber furniture.

The objectives of the research were to:

- Establish the current state of furniture manufacturing in Australia.
• Investigate the processing requirements for manufacturing complex furniture products on CNC equipment.

• Analyze the issues in current CNC manufacturing processes that inhibit manufacturing solid wood furniture components on CNC machinery with batch size one ideology.

• Evaluate current processing systems inclusive of part nesting for effectiveness.

• Perform a case study to establish World best practice in small batch manufacturing.

• Define batch size one.

• Investigate the conditions necessary for batch size of one to be effective inclusive of process planning, machine setup, tooling and related CNC machining sub-systems.

• Explore the factors affecting optimum cutting conditions of cutting tools on CNC timber cutting machinery.

• Explore further means of more effectively processing furniture components.

1.3 Research Methodology

The methodology for the work was to:

• **Research the development of CNC manufacturing in Australia.** A literature review was done to determine the historical context of CNC machining in Australia.

• **Gather commentary from and observe a wide cross-section of industry within Australia and overseas to establish best practice.** A list of companies in Australia and around the World was visited and
these are listed in Appendix 1. Companies and individuals interviewed are listed in the acknowledgements.

- **Establish current skills gaps relevant to CNC manufacturing.** Personal experience as manager of Victoria’s largest furniture training centre was considered along with commentary from key individuals involved with training program design. Australian Government Industry scans were considered.

- **Establish product suitable for batch size of one manufacturing.** Dr. Rado Gazo was consulted because of his work at Purdue University, West Lafayette, USA on small batch sizes. Several CNC manufacturers were consulted as to the viability of batch size one manufacturing. A small wine table was manufactured as a batch of one.

- **Assess small batch size methodology.** Interviews with machinery manufacturers and recognized training professionals were made, along with evaluation of existing small batch size furniture.

- **Re-design the processing of a sample CNC furniture component to demonstrate lean production principles.** A typical component manufactured as a one-off part was re-designed to be produced as a multiple component.

- **Assess CNC machining using nesting technology.** An industrial application was replicated to assess net benefits compared to pod and rail CNC machining.

### 1.4 Limitations

The limitations affecting this study were access to equipment, tools and software. In addition, access to furniture manufacturers around Australia was limited. The author was able to visit the manufacturers listed in Appendix 1. Dr. John Mo was able to provide concise background material on manufacturers in Australian
States other than Victoria. While Dr. Mo’s work was produced in 2001 it remains the most concise work to date on the status of the Australian Furniture manufacturing industry and the principal driver behind this study. Mr. Brett Moore and Mr. Antonio Di Conza were able to provide general advice on CNC processes through the Homag Australia group. Mr. Lee Gabbett and Mr. Mathew Gabbett provided general advice on CNC processes through the Gabbett machinery group. Mr. Chris Jones and Mr. Andrew Bismire provided advice relating to tools (cutters and saws) used on CNC equipment. Manufacturers in the state of Victoria, specifically the greater Melbourne area were largely used to reference this work. The author made extensive visits to Europe and the United States to visit Machinery trade fairs, CNC machinery manufacturers, training institutes and furniture manufacturers to determine what the state of the industry was there.

The studies and commentary contained within this document were based on a CNC machine that was determined by machinery suppliers to be of a common configuration for the furniture industry. Homag Australia advised the author, “Ninety percent of CNC processing centres sold in Australia are three-axis machines. Of the remaining ten percent, nine out of ten machines are sold with only a sawing option as the fourth axis.” The equipment used was therefore limited to the following configuration:

- Three axes (X, Y and Z)
- Table size 3 metres by 1.2 metres
- “Rail” type table
- Tubeless pod material supports
- Minimum 6 station rotary tool change
- Minimum 11 vertical boring spindles
- Minimum 6 horizontal boring spindles
- Saw blade or saw blade aggregate
The machine was located at Holmesglen Institute of TAFE (Chadstone Campus). While a quantity of existing tools were available for the study, an additional $6,000 was made available for the purchase of “leading-edge” tooling that would as far as possible enable most of the possible cutting conditions to be investigated. Leitz tools Australia (hereinafter referred to as Leitz) provided on loan specialist tools where identified to fully explore the potential of existing tool types for CNC manufacturing.

Software used in this study included:

- AutoCAD 2000
- ProCAM 2000
- Woodwop Version 4

AutoCAD was used as it is recognized as the World’s leading CAD design platform. ProCAM has been identified as a leading CAD-CAM manufacturing software program, and is used in numerous furniture manufacturing-training Institutes around Australia. Woodwop is workshop-oriented programming software for the “Weeke” and “Homag” CNC machining centres and was therefore provided with the test machine. It should be noted that Woodwop is windows based and is similar to all other programming systems used by other popular CNC machinery brands for data entry and process control.

The CNC processing centre (Figure 1) shows the second of two CNC machines used in this study. The equipment was purchased by Holmesglen Institute of TAFE and situated in the Chadstone (Victoria) workshops within the Furnishing Industry Design and Innovation Centre. This machine is a German-made “Weeke” CNC machine with a rail table, one routing spindle with tool change; vertical and horizontal drills and a saw-blade able to rotate 90 degrees.

This particular machine design allows for the cutting of solid wood where deep cuts are required. Off-cuts fall into the machine bed and do not come into contact with the moving cutting tool. Machines with a matrix (flat) table offer the best solution for flat panel work where the entire sheet is held by continuous suction
through a large vacuum pump. Both machine types were used to process furniture components using panel materials or solid wood.

Figure 1 CNC processing centre
2. Literature Review

The Australian furniture industry has been evolving since the mid-1980’s when the first CNC machines became available. Before that, furniture was made on static machines and although these have also evolved, the basic principle of each machine type has been the same since the first machines were invented. England and America were the birthplaces of the modern woodworking industry (Richards 1872). In 1793 the father of modern woodworking machinery, Englishman Samuel Bentham, invented the surface planer. In 1808 another Englishman, William Newbury invented the band-saw. The band saw’s widespread introduction was not possible until the development of French spring steel blades and cushioned wheels some forty years later. 1819 saw the invention of the copy lathe by Thomas Blanchard in the USA and Andrew Gear of Ohio patented the first spindle moulder in 1853. It is the spindle-moulder on which the modern wood-working CNC machine is based. With the development of the electric motor in 1873, machines became more efficient. In 1899 when ball bearings were introduced, machinery was able to meet the high quality and mass production demands of the period. By 1910, machine builders began to design machines with ball or roller bearings, and by 1920 the practice was widespread.

Green (2013) comments “We know from the data that the largest and fastest growing area of the World economy, for the last few years and for the foreseeable future, is in knowledge and intensive manufacturing and services. We can increase productivity growth not just in technical innovation but also with non-technical forms of innovation such as new business models, design quality, high-performance work, and management practices and systems integration.” The furniture industry has the technical expertise and equipment and needs to look at ways to implement manufacturing systems to harness the true value of that technical investment. A review of the technology of furniture manufacturing is essential to understanding the issues the industry currently faces.
2.1 Historical Review of CNC Technology

The American Electronics Industries Association describes numerical control (NC) as “A system in which actions are controlled by the direct insertion of numerical data at some point. The system must automatically interpret at least some portion of this data.” The McGraw-Hill multimedia encyclopedia describes CNC as “The method of controlling machines by the application of digital electronic computers and circuitry.” NC and CNC are processes where machine functions are controlled by letters, numbers and symbols that the machine interprets as mechanical functions.

Childs (1982) writes about the origins of NC (Numerical Control) as a result of the American military aircraft industry. At the end of the Second World War the United States continued the development of jet aircraft but the development of faster aircraft required more complex and demanding parts. Conventional means of manufacturing were falling short of the required tolerances and a faster, more accurate method of parts manufacture was needed. The film “The right stuff” chronicles the race to break the sound barrier and conquer space and it is within this time frame that the early history of CNC controlled manufacturing is set.

In 1948 John Parsons, director of the Parsons Corporation submitted a proposal to the United States Air Force for a machine to cut flat templates to inspect the contour of helicopter blades. He was awarded a contract to develop a numerically controlled machine with the Servo Mechanisms laboratory at the University of Massachusetts (MIT). In 1952 MIT successfully demonstrated a three-axis milling machine (Figure 2) that resulted in the Aerospace Industries Association recommending that all future machinery be fitted with CNC controls.
The machine demonstrated in 1952 looked very similar to a modern-day single spindle CNC router. Different were the banks of computer consoles needed to drive the servomotors, almost equal in area to the machine itself. All this was driven from a punched thesis tape, and became known as Numerical Control, or NC. Computer Numerical Control (CNC) was not to follow until IBM developed the personal computer.

Development in the wood working industries began in the mid 1960’s with the first pressure beam saw, and a few years later the Ekstrom Carlson Company offered the first NC router in the USA. The Japanese Heian Company developed its first NC router in 1968 and in 1969 the Japanese Shoda Company (Figure 3) claimed the first “circular-cutting” NC router. Early machines of the NC type relied solely on a punched tape to transfer the program to the machine, hence the term "N.C." No calculations or modifications were possible. NC routers using punched thesis tape would need a new program and hence new tapes if any modifications were needed.
Susnjara (2006) asserts the American Thermwood Company claims the first CNC (Computer Numerical Control) machine, based on the Intel 8080 chip. Unlike NC, a CNC machine is able to perform some calculations such as acceleration and deceleration of the axes, and offer modification of programs at the machine control. These early CNC routers used G-code as a programming language, and this is still used today on all CNC wood working machines where routing is performed. This code is usually not displayed on the screen anymore, but it's still there. The code is located in the files that send signals to the servo motors.

The rapid development of the last twenty years has begun to slow and the furniture industry is experiencing a period of refinements. Recent developments are cheaper CNC machines (inclusive of 5-axis CNC equipment), increasingly user-friendly program design and data-entry, and high-speed spindles. Anecdotal evidence from CNC machine manufacturer’s reveal that aggregates providing additional machine functions will be in the minority as five-axis machinery gains popularity, even in Australia. However this equipment falls outside the scope of this study.
2.2 Point to point and continuous path milling

Early CNC machinery fell into two categories; point to point and continuous path milling. "Point to point" CNC machines were traditionally drilling machines where the tool is directed to a specified point on the worktable. Both X and Y axes moved at the same speed and it will be likely that one axis will arrive at its programmed position before the second axis. Here the machine tool performs a pre-determined function, usually to drill a hole, or series of holes depending on the configuration of the boring spindles. The position codes are sent to each of the two drives (X and Y) relating to width (X), and length (Y) within the Cartesian co-ordinate system. The system was developed in 1637 in two writings by Descartes. In the second part of his discourse on method, Descartes writes about specifying the position of a point on a surface, using two intersecting axes (X and Y) as measuring guides. The height of the drilling unit remains constant until a further command (Z) to perform the drilling action was sent to the vertical spindle drive.

Software to operate point to point machines is simple in function and easy to use. These machines used a proprietary controller and software and programs developed for one machine brand could not be used on another. This situation has changed and now Windows-based software is used that allows the transfer of programs through generic AutoCAD-format files. This “open-architecture" software compliments the use of CAD CAM programs.

Continuous path milling machines use a fluid three-dimensional movement of all three machine axes to direct the tool. The speed of both axes will be adjusted in order that the tool moves either in a straight line, or arc, to its programmed position at the programmed feed speed. This category of machine was usually described as a “routing" machine and was used to mill parts, originally for the aviation industry. The software controlled more of the machine functions and was more demanding on the operator than point to point software.
2.3 Common machine types

In the furniture industry since the mid 1980’s, these two machine types have become similar in appearance and function. The “point to point” machine is still lighter in construction, and is usually equipped with either a rail or matrix (flat) type bed. A rail bed has six or more moveable rails on which the component is held, usually with vacuum pods and is more common in the solid timber furniture industry. The matrix table is gaining increased acceptance due to the industry’s adoption of American-developed “nesting” operations. The matrix table is a flat surface on which sheets of manufactured board are laid and processed into panels for kitchen, bathroom and office furniture. This is a simple batch size one process.

A woodworking “CNC router” is depicted in (Figure 4). This machine is traditionally much heavier in construction and is mainly used for profiling operations. The addition of drilling and sawing functions adds considerably to the cost of this much more expensive machine type. An exception to this are the numerous low-cost “flatbed routing machines” popular in Australia. These machines are manufactured around the world as a cost-effective substitute to traditional routing and profiling machinery and used mainly for kitchen and bathroom cabinetry and office furniture, using mainly manufactured board.
The Australian furniture industry, dominated by small business traditionally purchase equipment on price. It is agreed by suppliers that in the 1980's and 1990's, rail machines based on the “point to point” machine type constituted in the vicinity of 80% of the CNC machines used in the furniture industry in Australia. Traditional CNC routers and low-cost flatbed machines took up the other 20%. The advent, popularity and success of nested-based manufacturing in Australia since the mid 1990's have led to a turnaround in machine type installations and (according to anecdotal statements by the major suppliers) the flat bed (matrix) table machine now accounts for over 90% of all CNC machines sold in Australia.

Figure 4 CNC Wood working routing machine
2.4 CNC manufacturing skills gaps.

In addition to the state of formalized industry training, the Australian furniture industry has problems attracting the best people needed to operate high-end CNC equipment to its optimum performance potential. This is primarily as a result of low wages and the perceived low regard of factory work. This situation seriously inhibits the adoption of small batch sizes. There are limited skills in efficiency in CNC manufacturing through innovative use of cutting tools, use of software, small batch sizes and job fixturing. This chapter explores some of the CNC manufacturing issues that manufacturers using CNC equipment must solve to improve cost-effective product output.

Training is essential so management, programmers and machine operators are able to make the best use of this expensive equipment. Bob Davis (Davis furniture, Victoria) said, “The right person is able to double the productivity of our CNC machines.” Manufacturers struggle to attract clever people to make the
most of their equipment. CNC training in Australia is structured around actually operating the machine and the machine supplier usually provides this on machine commissioning. This initial training may be of limited value because all CNC machine suppliers are extremely busy. (Machine) supplier training is very focused on the company's immediate needs. In two or three days, employees will be able to start the machine, make some minor adjustments and write basic programs on machine-specific software. It takes time for a person to develop, but the demands of manufacture usually mean that employees spend their time repeating the same jobs over and over and eventually stop learning.

The state of the industry can be linked to vocational education and training institutes (TAFE’s) where training is delivered for a total of 80 hours on CNC machinery, and 40 hours on CAD and CAM software. This limited training schedule is not taken up by all trainees due to the equipment not being available in all TAFE Institutes. In addition, the various TAFE's own different types of equipment, some of it unable to offer the depth of training for students to operate the various CNC machinery types currently in use in Australian industry. As learning units (competencies) in CNC machining are optional for cabinet making trainees, many Companies do not select these "elective" units, especially if the Company does not currently own CNC machinery.

There are few manufacturers who have the time to allow their operators to "play" around with the CNC machine to see what else it can do. Running new jobs is often a slow process as the programmer is often unsure of the full abilities of the equipment because they have never really pushed its capabilities. Many CNC operatives are able to use a machine because they have done it before, but don't really understand what makes the machine work, and the capabilities beyond their own immediate manufacturing environment. This situation inhibits the adoption of new manufacturing techniques such as batch size one.

2.5 Definition of Batch size of one (BS1).

The manufacture of furniture in Australia has moved from high volume for stock, to low volume for immediate assembly and dispatch. This is achieved in batches
of separate parts and moved from one process to the next within the factory. The Company’s timely response to the customer’s order and the ratio of value-added to non-value-added work are prime concerns for the manufacturer. AWISA (2013) p.3 states “Non-value added activities make up one third of all time spent.”

Khan et al. (2002) stated “In a JIT manufacturing environment, a supplier is expected to deliver goods frequently in small lots. Ideally, a supplier to the JIT buyer is expected to synchronise his production capacity with the buyer’s demand so that the inventory in the supply pipeline is reduced and eventually eliminated. The aim is to achieve single-piece flow where a single discrete unit of product flows from process to process. Ideally, the batch size is one.” Reducing the batch size is therefore a desirable objective.

While batch size of one has no clearly defined definition, it is the perceived goal of every manufacturer seeking to apply lean manufacturing principles to their product. “Towards a batch size of one” is the reality with the actual batch size for a particular enterprise being optimal after considering all production variables.

2.6 Buying CNC Machinery

In the late 1980’s the West Australian Furnishing Industry Training Centre reported a manufacturer producing drawer and door faces one at a time on a single turret-head CNC router. The manufacturer stated that the machine had “increased our production in some cases 300 percent”. In this case a similarly costed machine with four parallel heads capable of routing four doors at once would have been more efficient; producing four doors (or drawer fronts) in the same time the turret machine could produce one. In Victoria a bedroom furniture manufacturer uses a CNC machine with two cutter-heads but the machine table can hold 4 to 8 separate components. These two situations illustrate that manufacturers often purchase the wrong type of machine for the jobs they produce.
Getting the right machine can contribute to the growth of a Company. The wrong machine could be inefficient and contribute little to a lean manufacturing system. Australia is one country where high technology is receiving particular interest. A large amount of CNC machinery has been installed over the last 30 years. New technology could be purchased without much thought, however, and in some Companies the CNC machine soon becomes a very expensive work-bench.

Australian manufacturers purchase CNC machines to replace static wood working machines. The result of this narrow thinking is that work practices on CNC machines resemble work practices on static wood working machines. Manufacturers may in some cases adopt the automotive-style Kanban systems pioneered by Toyota. Kanban is widely known in manufacturing circles but the core principles are worth stating and these are:

1. Visualise the work. Observe the work flow through the system and see the bottlenecks, work-blockers and queues.

2. Limit the work in progress. Limit unfinished work in the system to reduce the time taken to travel through the system.

3. Focus on flow. Use work in progress (WIP) limits to optimise the system and improve the flow of work, collect production data and obtain indicators of possible problems.

4. Continuous improvement. Measure the effectiveness of the system by tracking work flow, throughput and quality.

Furniture manufacture in Australia is characterized by stacks of timber waiting to be machined and pallets of semi-finished parts moving slowly from one work-station to the next. CNC machines have the capacity to reduce batch sizes, cut down on inventory and speed up production. Retailers demand small deliveries of custom-made furniture to meet immediate demand and carry very little stock to reduce their overheads and storage problems. The Australian furniture manufacturer is carrying the retailers’ problems by over-producing to meet
expected demand (orders). The CNC technology is capable of changing this scenario.

2.7 Selecting CNC machines

Gola et al. (2011) describes a four-stage methodology for the selection of a machine tool (machine) for a focused flexibility manufacturing system. Stage one is the gathering and processing of information about the available machines; design knowledge and technical assumptions for the products to be machined. Stage two is the elimination of machines that do not meet the criteria of critical technical and organizational conditions. Stage three is the development of possible variants of machining the required products. Stage four is the analysis of the variants according to optimal criteria. Simplified, the selection process is to see what is available; eliminate any that do not meet the criteria; from the rest, see if there is any machine that can improve the production and select the optimal solution from those.

Within this selection framework there are a number of questions that should be answered. What does the manufacturer make? Is he/she an existing or new CNC user? What tool holder system is currently being used? How many hours per day will the machine work? What is the percentage of work that is flat panel and solid timber? What is the smallest component size? Are there any difficult component shapes or sizes? What are the special clamping requirements and maximum work-piece thickness? What is the biggest number of tools required for any one job? What is the maximum tool or aggregate diameter? Are angle drive heads or sanding units required? Are the operators experienced in programming and is the Company using a CAD package now? Finally, what is the investment budget?

CNC machinery is designed to run around 50% of the time according to advice by the major suppliers. This workload will give six to eight years life from the investment. The Company accountant may want to write it off long before then. The Company may also wish to take advantage of new technology before this time. If the Company runs the machine more often, they may get only four years, and at this usage may want to think about stepping up to a model that will
provide additional processing options. First time CNC buyers tend to go in with a price in mind, but experienced users generally know precisely what they need and tend to spec up the new machine to suit their present and perceived future production needs.

A CNC purchase should be based on a thorough investigation, and identified in a business plan. It should not be based on emotion, friendships or “special deals”, but what is right for the Company at the time. Some purchasers have said they only looked at two machines. Can an informed decision be made with such a limited investigation? They also say they invested because “It was time” or “We wanted to keep up with our opposition”.

For a kitchen and bathroom manufacturer a flatbed CNC router will enable the dividing of parts with a rotating cutter. The kitchen or bathroom cabinets are developed from a software program and the entire library of parts is sent to the machine as sheet layouts. All of the parts for the entire kitchen are cut from several sheets of manufactured board. This is the simplest form of batch size one practiced by Australian “furniture” manufacturers.

For a manufacturer working mostly in solid timber a rail machine will be most appropriate. Joinery manufacturers will also benefit this machine type. A rail machine will hold the material off the table and allow for deep cuts and offcuts to fall away from the machined parts. The condition of having the component 100mm above the work table also allows for “stacked” tools to be used.

One of the main issues that must considered is whether or not the new machine will fit into the production system. A new CNC machine will need travelling and working speeds to keep pace with these projected working cycles. How many hours a day will the machine work? Is the current production rate able to keep the work up to the new CNC machine? It’s no good having a CNC machine that will do “X” amount of work if your other equipment is not capable of supplying this amount on a consistent basis. In some cases it may be better to get a slower or smaller machine that “fits” the manufacturing needs better.
2.7.1 Flatbed machines

Machines for nested-based manufacturing are usually “flatbed” Numeric control machines and the more traditional (in design) CNC flat table “point to point” machines. Flatbed machines are based on a welded steel frame, a flat vacuum table and an overhead gantry supporting a cutter head. The advantages of using a low cost machine with the Nested-Based process are readily apparent. The method vastly reduces handling of sheet materials. There is a marginally higher yield per sheet from a routing machine when compared to a saw. There is greater accuracy than with stand-alone machinery resulting in improved product quality. There is a smaller cost for one machine only and, increased safety. Most of the flatbed routers come in a range of sizes, are fitted with tool magazines and often can be supplied with automatic loading of sheet materials and unloading of finished panels. Some flatbed machines have multiple drilling heads but most rely on single tools held in an ISO tool holder.

A nested based work cell includes a set of feed tables that are fitted to the CNC machine. The “cell” enables the machine to automatically feed panels to the machine and then slide them off the table when the job is finished. The system may vacuum (clean) the table ready for the next cycle. The nested based work cell will double the floor space the equipment takes and will add to the initial cost of the machine but the benefits will be evident in terms of labor savings.

In terms of production of products based on flat panel materials, the nesting type machines are capable of producing a batch size of one. Parts are nested together and while the common practice is to get as many parts from the sheet as possible, resulting in parts for more than one job, it is still possible to nest the parts for only one job as shown in Figure 6.
2.7.2 Point to point machines

Traditional (Often Italian or German-made) CNC “point to point” machines capable of Nested-Based manufacturing are available at an increased price point compared to locally sourced CNC flatbed equipment. Some of the small point to point machines have positioning speeds of around 80m/min. They will have a rigid base for the high-speed acceleration of the machine axes. The drill bits could have variable rpm and if any routing is required, the machine is supplied with approximately 8 tools (depending on machine type and brand) with rapid automatic tool changing. This is about as many tools as a manufacturer will need for nested machining. A mid-size machine is provided with at least 10 tools and a positioning speed of around 100 m/min. A large machine will go beyond 100 m/min and can have as many as 60 tools available. See Figure 7.

If a manufacturer needs to use large diameter tools, the tool-changer may require a vacant slot either side of the larger tools so the tools won’t crash into each other. This may mean that fewer magazine positions are available for tools and may need to be considered on purchase. An aggregate is a special tool such as Figure 6 Nesting of parts for a batch size of one
a horizontal mortice or snipping (sawing) tool and an aggregate saw can be seen mounted in the spindle in Figure 7. Generally, a tool magazine carried on the work-head will change tools the quickest. A magazine on the rear of the main (travelling) beam will be slower (minimum 7 seconds) and a magazine mounted external to the machine itself will be the slowest. Tool change speed is important as it affects the job run time. Positioning speeds only assist with sending the tool to the job and this is a small part of the process so manufacturers should not be too concerned with extremely high positioning speeds. It’s the actual cutting that takes up most of the processing time so getting good tools into the material will speed up the “real” work on the CNC. Finances spent on high quality tools will vastly improve the performance of any CNC machine.

![Figure 7 Tooling on modern CNC machining centre](image)

A manufacturer working mainly solid wood will want to consider a rail machine. The rails are positioned along the length of an open bed and support the material on “pods.” These pods hold the work about 100mm off the table and off-cuts drop into the well of the machine. For deep cuts and design-oriented work, the rail machine has some advantages. These are the increased cutting height, the
ability to apply larger-diameter tools all around the work-piece and the ability to work freely on five faces of the work-piece. A machine of this type will come with many tools, multiple drilling heads, saws and other devices such tracing heads and sanding units. Some machines are available with 4 or 5 simultaneous movements. Anecdotal evidence from suppliers indicates that one in ten machines have four axes and there is an increasing use of five axes machines in the woodworking trades.

**2.8 Buying a CNC machine, some questions**

The CNC machine depicted in Figure 1 was installed at Holmesglen Institute. A selection process was undertaken to identify a machine that would meet the requirements of the department at present and also to provide for future needs. A number of important criteria were considered to produce an initial list of potential equipment from which a suitable machine could be selected.

To review current thinking leading industry personalities were consulted. These were Mr. Brett Moore, Wood working industry consultant and previous sales consultant for Homag Australia; Mr. Eberhard Schie, Export Manager (Asia-Pacific) Homag machinery; Mr. Dave Dunn, British Columbia Institute of Technology; Mr. Bill Rolfe, Furniture Industry Research Association (FIRA) United Kingdom and Prof. Iain MacDonald, Associate Director, Centre for Advanced Wood Processing, University of British Columbia, Canada.

**Firstly**, what does the manufacturer do? What do they make and what are the things that they would like to do if they had the equipment? The requirements of a shop-fitter are different than those of a stair-builder, kitchen manufacturer or solid timber furniture maker. The product will determine if the machine should have a flat bed or rails, the capacity or size of the table and the type of tool holder. These will all be different for each type of manufacture. A manufacturer needs to know how big their new machine needs to be and what depth of cut it needs to have.
Secondly, is the manufacturer an existing user of CNC machinery or is this going to be the first machine? If they are an existing user they will already have a machine and therefore some expensive tooling. They will also have employees skilled in using the CNC equipment. The new machine should preferably take advantage of these existing resources. They will have formed opinions on how they work, what is best for their Company's production and the direction they wish to go. While a Company should always be open-minded when investing a large amount of capital, existing convictions and opinions are hard to ignore.

Third, a Company needs to consider the volume of work that they are currently doing and what their future targets will be. A Company's new machine will need travelling and working speeds to keep pace with these projected working cycles. How many hours a day will the Company work the machine? Are they able to keep the work up to the CNC machine? The other equipment and processes in the Company must be able to supply the new CNC machine on a consistent basis. The same issues arise if the new machine will be capable of producing much more work than the factory is capable of handling. In each case it may be better to get a slower or smaller machine that “fits” the factory production requirements better. If the cutting plant (saw) is supplied by a particular company, the Company may consider buying the CNC machining centre or router from the same Company to centralize the servicing and maintenance. In other words, deal with one supplier rather than three or four. A Company may also find they get a better deal as their relationship (or partnership) with a supplier grows.

Fourth, a Company needs to consider the type of material that they will process on the machine. How much work is flat panel and what is the weight of this material? How much is solid timber and what are the dimensions? What are the smallest sizes? Are there any difficult to hold pieces that might need special clamping? Are there any other materials that they may be able to use in their product? The Company would be well-placed to plan to improve their product if they are going to invest large capital in a new machine. The investment will not stop with the machine purchase. There is the question of staffing, the tools
required, dust extraction, the air supply and the maintenance issues that a machine of this type brings.

**Fifth**, what sort of processes will a new CNC machine be required to do? A CNC machine is capable of drilling in the surface and four sides of a square panel. It can perform routing operations on the edges and surface of the board or timber panel. The machine could be capable of sanding the product, applying saw-cuts along and across the board, mortising and tenoning, dovetailing, slotting and grooving etc. In addition, many of these tasks can be done on panels that are not square, in other words, on another (or fourth) axis.

**Sixth**, what special machining is required? If the Company is a kitchen cabinet manufacturer they may need to manufacture mason’s mitres. They may need to join bench-tops or drill many holes in the case of a manufacturer of wall units. Does the Company need to machine mortices or complex machining to join material together? Does the Company need to make thick components that require angled cuts; this may necessitate a machine with high vacuum cups and a deep bed into which off-cuts can be collected. This question also takes in the type of software that may be required. There is software available from machinery suppliers or in partnership with software companies. Software is available for kitchens, furniture, stairs, doors architectural applications; the list is extensive.

**Seventh**, what is the Company requirement for CNC tools? What is the largest number of tools required for any one job? Tools are expensive and any Company needs to use as few as possible to get the profiles and machining required. If ISO or HSK tool holders are already available, the Company may want to make sure that any new machine purchase accepts the same tool holders. What are a Company’s largest diameter tools; the larger the tool the more likely it will be that not all the slots in the tool magazine can be filled. In addition to traditional routing tools, CNC equipment is capable of holding “aggregates” or special working units capable of four and a half axes for routing and sawing.
Eighth, is the Company able to consider a nested-based manufacturing solution? 90% of new installations are nested-based. This technology is not suitable for all applications but it has become a standard manufacturing style since the mid 1990’s. It is a good idea to look around, ask a lot of questions and seriously consider whether or not a flat table or rail machine (or a combination) is right for a Company.

Ninth, how skilled is management or their employees at programming a CNC machine? If the machine is the first CNC in the Company, the following questions could be asked: Who will prepare the programs? Who will run the machine? How easy is the programming unit to learn and use? How will I get my production drawings or those of my customers to the machine? How long will it take my staff to learn the machine and how willing are they to use the new technology? Will new staff cost me more and are they available?

Tenth and finally, do I have the services necessary to install the new machine and get it operating in good time? A Company will need an area of floor space to site the machine and to move and store materials. The machine must be sited in a location that allows good material flow through the factory. Management needs to provide compressed air at the rate specified for the machine being considered. Management should have dust extraction, materials handling and floor loadings to consider before placing a machine order.
2.9 CNC Terminology

A significant component of the set-up time of a CNC machine is setting the holding devices (jigs) and inputting the program. A basic understanding of programming conventions is required. A CNC machine will have the possibility of allowing program modifications at the machine control often referred to as the "interface". This interface will be a program (or series of programs) that are designed to operate the machine through a windows® operating system. Graphics; or pictures, run the windows system and this is referred to as a GUI or graphic user interface. Most CNC software takes advantage of this environment.

It is possible to develop programs using the CNC machine's own software. This software is used to write drilling layouts and routing programs based on end points of arc's or lines. It is effective for most basic processing requirements. Lines or arcs are entered sequentially from the start of the profiling operation. A drawing is not required for this process. Here the machine movements are expressed as “absolute” (where end points are measured from the program origin) or “incremental” where the points are expressed as actual machine movements. The introduction of “parameters” or “variables” has significantly improved the effectiveness of these programs.

A parameter is a self-defined formula. Basic parameters are taken from the panel-input size. A 600mm long panel will therefore have an X value of 600, X being the designation for any measurement along the length of the panel or component. Every time an X is used in that particular program, it really means 600. Using basic math's it is seen that X/2 (X divided by two) will be 300. A drill bit or routing located at X/2 will always be in the centre of the panel no matter how long the panel may be. A parameter can also be defined by the programmer. An example would be A=X/2 and the result of this parameter would be that when the "A" was used, it would represent X/2 or panel length divided by two. Further to this, another parameter could be written B=A/2 When "B" is used; the meaning would be half the length of "A" or a quarter of the panel length. Parameters can be quite complex, but greatly improve the flexibility of CNC machinery. A
parametric program to cut a circle can be used to cut any size circle on the machine. At the same time a drilling pattern can be developed that will suit any size panel simply by changing the panel dimensions. Even the number of holes or types of routing can be altered simply by changing the panel dimensions, or entering any user-defined parameter.

Some parameters can be written into sub-programs (routines) that can be added to any main program. It would therefore be possible to write a main program for external profiling of the work-piece, then add an external (previously written and stored) sub-program to perform drilling, hinge boring, morticing and other commonly-used machining functions. These sub-programs would have sizes determined by parameters set in the main program. The benefits to batch size one production are that these sub-programs are written only once, and then used for the life of the machine. Modification of drilling patterns can be achieved for every part in the furniture "library" of the Company.

Conditional program lines can also be written. An example would be when a hole is programmed, conditional on the panel being over 600mm in X (length). Panels less than 600mm in length would therefore be produced without the hole. This is useful for cabinet doors to fix the number of hinges dependent on the length of the door. Taller doors receive the machining for more hinges without any operator input.

For more complex programs CAD is used. “CAD” is Computer Aided Drafting (or drawing) and the most widely used software of this type is the AutoCAD® program. For manufacturing purposes alternative software has been developed that ideally suit part processing. These CAD-CAM programs combine the drawing capabilities of AutoCAD with a “CAM” (Computer Aided Machining/Manufacturing) function. Here the part drawing can be post-processed for the particular CNC machine, adding complex tool-paths, tool changes and other machining functions such as pockets and three-dimensional routings. When CAD programs are used on a CNC machine, it may not be possible in
every occasion to modify that program on the CNC machine. Editing may (not always) need to be done with the CAD system that created the program.

Whatever brand of software is used, the part drawing must be transferred to the machine. This is done with a “post-processor”. This is software that converts the line drawings into machine code. The most common form of machine code is “G-code” and this text-format code has been used since 1952 when the first NC machine was developed. Recently, woodworking machinery has been made available with machine-specific code formats and it is possible to post-process to these formats as well. In most cases, software that can save drawing files in a “neutral” format (DXF is widely used) is preferred. DXF is a file format developed by AutoCAD and most machines will accept this type of file.

Once the file is ready for the machine it must be “downloaded.” This can be done with a floppy disk, memory stick or cable to link a single computer to the CNC machine. A LAN (local area network) connection may be used to access files directly from the CNC machine. Once the machining cycle has been started other programs can be downloaded or developed at the machine.

Where multiple CNC machines are used, consideration should be given to software able to transfer data between the various pieces of equipment. This can be done with a LAN, or with the use of a barcode printer and reader. With this in place a manufacturing “cell” is created. Some companies refer to a cell as a single CNC machine with a sander, band saw or some other equipment located close by that the operator uses while the CNC machine is processing product. Another type of cell is where several CNC machines are linked into a production unit capable of flexible, high-volume part processing.
2.9.1 Programming conventions

When an employee in a furniture factory sets up a CNC machine for a production run, several things need to be done. First, a suitable jig must be manufactured, or selected from several that have been used before. If a jig is not used, vacuum pods or other holding devices must be set according to the machining cycle. Next, the appropriate cutting tools must be selected and loaded into the tool magazine if not present already. Finally, a CNC program must be selected from a storage device. If a program does not exist, one must be written. It is here that the CNC machinist will demonstrate some skill in developing a CNC program using a CAD software program, G-codes or the machine’s graphic user interface (GUI).

It is this machine code that drives the machine. The ability to read and write code is a bonus for any CNC programmer. Some users have found it just as easy to write the machine code themselves, claiming they have “more control over the process”. While CNC code differs slightly between machines, there are some basics that every programmer (and management) should be aware of. Any program can be broken down into three elements. The mechanical functions, the direction each of the three axes will move, and the way these movements will take place. Following is a brief description of common CNC machine code.

2.9.2 Machine code within the Cartesian Co-Ordinate System

Mechanical functions are often expressed as machine codes and these are articulated as M codes. These codes turn things on and off. Items to be turned on and off will be motors, vacuum pumps and other mechanical devices. These are allocated by the machine manufacturer, and vary from machine to machine. There are usually only a handful of M codes for each CNC machine.

The direction of movement is expressed in X, Y and Z values. These are the axes of the machine. Usually the X-axis is left and right; the Y-axis is front to back. The Z-axis is always up and down. The X and Y axes have been known to be different on some brands of machinery. This system was developed by the
French mathematician Rene Descartes and is called "The Cartesian co-ordinate system" after him. See Figure 8.

A number always follows the X, Y or Z-axis, being the value of the movement. Such a code could be X550.50 Expressed as a value from the machine origin (where the panel meets the pop-up panel stops) is an absolute value, the CNC code being G90. The value of the end point of the movement can also be made from the last point of the tool.

![Cartesian co-ordinate system](image)

Figure 8 Cartesian co-ordinate system

This is the travelling distance of the tool and is an incremental value, the CNC code being G91. For example, a line of CNC code that reads “G91 X550.50" would mean, “move from the last point 550.5mm in the X direction”. Adding further information such as a depth, feed speed or radius (in the case of an arc or circle) will develop the program still further.
2.10 Tooling for CNC Machines

A CNC machine can cost anything from $60,000 to over a million dollars, yet $20 cutters are still commonly used to manufacture product. While this is possible, one must question the economics of such a decision. Naturally, for one or two pieces a low cost tool should be fine but when production volumes are considered, manufacturers should be considering tool life, accuracy and performance. There are several quotes from the Leitz Company’s internal training literature that are worth considering. The first is “Any wood working machine is by the nature of its design a tool holder and, therefore cannot perform as intended without the correct tool.” This is particularly true of an expensive CNC machine. The machine moves the work and the tool to various positions within the work area and the tool does the work. The robust nature of the machine is such that it is capable of operating speeds far beyond that of a $20 router cutter.

2.10.1 CNC Tool holders

CNC tool holders are used to attach the tool to the machine spindle. There are two common types used in Australia. The first is the ISO-30 and is shown on the right of Figure 9. The second type is the HSK-63 and two are pictured (left and centre tools) in the same Figure. The tool on the left is a long design and rarely used. The short design HSK and ISO are the two common tool holders. All three of these example tool holders use a nut and collet to hold the cutter in the tool holder. The tool is therefore held in the tool holder by friction. It is widely accepted that many low-cost CNC flat-bed routers are fitted with motor and spindle provided by a few specialist suppliers. These motors can be fitted with ISO or HSK spindles but the more common type found in Australia is the ISO type.
The difference between the ISO-30 and HSK-63 is that the ISO-30 tool holder is held by the pin seen on top of the tapered shank. It is held in the spindle by friction against the taper. The HSK-63 tool holder is held by fingers gripping the inside of the chuck and held flat against the end of the machine spindle. Literature supplied by both Leitz and Leuco tooling manufacturers support the HSK-63 as the most accurate and true-running (concentric) chuck (tool holder).

According to research conducted by Leitz, tools held “normally” in either an ISO or HSK chuck have a runout of .025mm. A “normal” chuck is one where a lock-nut and collet is used to secure the cutter. On a cutter with two cutting blades, this means that only one blade will be actually cutting the wood. This was demonstrated by trials run using basic cutting tools see chapter 5.2. This affects the quality of the work-piece, in fact, a reduction of 50% of the intended and designed performance of the cutting tool. Leitz has also determined that a chuck clamped using either hydro clamping or pressure clamping (no lock nut) reduces
the run-out to .003mm Tools held in these chucks will produce higher quality work and last longer.

Using a tool holder on a CNC machine without a lock nut also improves the dust extraction as the chips flow easily past the slimmer tool holder. Figure 10 shows the path of chips generated by the cutting process. Chips are extracted through the dust collecting hood in an upward direction. It was observed through the numerous cutting processes during this study that less dust and wood chips were evident when cutting with friction tool holders (right) than with tool holders where the cutter was held with a collet and nut (left).

New tool holding technologies such as the Leuco “Tribos®” and Leitz “Thermogrip®” The tool pictured on the right is beneficial in reducing run-out to the levels possible with the traditional hydro clamping system. The hierarchy of tool holding systems is as follows (best to worst):
- Mono-block tool (Tool mounted directly to the spindle interface) not used in Australia.

- Hydro clamp chuck AND Tribos or heat shrink chucks (Figure 11)

- Balanced collet chuck

- Unbalanced collet chuck (least effective in reducing Runout)

Traditional collet chucks have been tested to a Run-out value of .025\(\mu\)m. (25 million parts of a metre, or 25 thousand parts of a millimeter). Technical advice supplied by the Leuco Company is that 15 \(\mu\)m run-out is the limit for good cutting quality. Hydro and “Thermogrip” type chucks tested to a run-out value of 3 \(\mu\)m. However, hydro chucks are three times more expensive than Thermogrip or Tribos type chucks and the feeling is that in time the industry will more readily adopt the new chuck technology to reduce costs.

![Figure 11 Non-nut tool holding systems](image)

The two tool types shown in Figure 11 are both held by friction between the tool and the body of the tool holder. No collet is used and therefore the runout is reduced. The Tribos (left) tool is inserted into a tool setting device that compresses the triangular shaped shank holder and allows the tool to be inserted. With this technology, the tool shank is held by three points but the tool spins concentrically. The tool set machine is shown with the three pressure
clamps. The Thermogrip technology uses heat to expand the tool body and allow the tool to be inserted. When the body cools, the tool is held concentrically.

2.10.2 Cutting tool material

Around 1950, high-speed-steel cutting tools were widely used. Within ten years the Tungsten Carbide tipped cutting tool had become the tool of choice, lasting ten times as long as the HSS cutter. In the early 1970’s the Polycrystalline Diamond (PCD) tool was developed and raised the performance to 100 times that of the TCT cutter. The Monocrystalline Diamond tool raises that again to 1,000 times the life of the TCT equivalent. Refer to Figure 12. This means that for every diamond cutter that is used, a manufacturer would need 50 TCT cutters, assuming they could sharpen each one 20 times (they probably couldn’t as the 20 times is recommended by the tool maker and may not be relevant to the enterprise). If the TCT cutter cost just twenty dollars and the Diamond cutter cost $1,000 then the manufacturer has spent exactly the same for the cutter(s). What they have yet to consider is that the 50 TCT cutters will have cost in excess of $20,000 to sharpen (20 times each) and the manufacturer would have lost 166 hours of machine time, or over four weeks of production just changing the cutters.

![Figure 12 Life of cutting tool materials (Courtesy Leitz)](image-url)
Polycrystalline diamond (PCD) tools are used for machining hardwoods, but softwoods contain more defects (knots) and are considered unsuitable for processing with PCD. PCD tools are ten times more efficient in eliminating heat due to friction meaning there is less burning of the cut edge. PCD is used at higher RPM’s to improve edge quality, but not to achieve a higher feed rate.

There is another quote from the Leitz tooling Company “An increase in the flexibility of a manufacturing process can often be accomplished by making improvements in the performance of its tooling.” One higher performing tool is the (Leitz) “Profix” (Figure 13) tool body capable of accepting different profile inserts. The insert is quickly located into the body of the tool and is locked into place. The attractive aspect of this system is that the freshly-sharpened cutter face is always located against a pre-determined stop and always produces the same profile no matter how many times it’s sharpened.

![Figure 13 Leitz Profix tool](image)

Every time the cutter inserts are sharpened the manufacturer achieves the exact same result as every cutter sits against the same vertical and radial stops.
Different shapes can be used without changing the tool data in the computer as the minimum radius of every tool profile is the same. The process takes only a few minutes and the enterprise can change from a bull-nose to a lambs-tongue with absolute security and confidence. This is an example of flexible manufacturing and even though the inserts cost $400 each, the savings in time and quality justify the expenditure. Manufacturer’s working towards small batch sizes will benefit by the use of this type of quick-change tooling.

There is a third quote from the Leitz Company’s internal training literature that is worthy of note. It is that “The potential for cost savings through better tooling goes far beyond the obvious of reducing Company expenses through less grinding and fewer tooling material purchases. The most significant savings are realized through increases in production times and lower reject rates.” Some time ago the author was involved in machining trials on 15 species of Australian hardwoods. Ozarska et al (1998) determined that the geometry of the tool affected the reject rates on many of the differing species of timber. It was found that by altering the cutting tool geometry, the reject rate was reduced to almost zero. This attests that research can improve cutting performance and reduce the need to re-machine or replace damaged components.

After a Company has purchased quality tools, a suitable allowance must be made for the proper maintenance (sharpening) of that tool. TCT cutting tips have improved in performance many times since they were first introduced in the early 1960’s. Development in fine-grain carbides have meant that a typical cutter will last almost twice as long as they used to. Sharpening the cutting edge to a micro-finish will quadruple the life of the cutter. Correct sharpening of the quality cutting tool is essential to maintain the performance of the tool design and maintain the benefits of its longevity. The latest tooling development was shown at the German "Ligna" fair (2013). The Leitz Company is now able to coat the cutting tool with a wear-resistant (proprietary) coating that improves the service life of the tool. Recent (since 2010) reductions in the volume of Carbide available Worldwide has meant increases in the cost of cutting tools as carbide prices
increase. Coated tools are one possible solution to this limitation of supply, mainly from China.

Cutting tools will be used according to the limitations and settings supplied by the tool manufacturer. The recommended maximum RPM for a CNC router bit will be supplied by the manufacturer and must never be exceeded. Litigation between Worksafe (the Australian workplace safety authority) and a tooling manufacturer where a tool was sold without a recommended safe operating (RPM) speed resulted in the cutter separating from the tool body and an operator became deceased as a result of contact with the ejected cutting tool. The tool was operating beyond limits that would have been set by leading tooling manufacturers, based on a tool with similar configuration (length, weight, projection).

In some cases a recommended feed speed can also be provided but this can be dependent on the material being processed and the depth of cut. This can be a learning process for first time users. It may be necessary to experiment to find the best feed speed for the desired finish. There are no new secrets in machining wood. What worked 50 years ago still works today and a cutting speed at the cutter tip of between 40 and 70 metres a second is optimal. A chart explaining this is available in the Leitz “Lexicon” and is reproduced in Appendix 2. Referencing this chart it will be found that a 20mm diameter cutter spinning at 18,000 RPM is cutting at 10 metres per second at the tip. This is below the optimum cutting speed by a significant margin. At this RPM (referencing the chart) a cutter with a diameter of 60mm is required to provide the best cutting speed at the tip.

To raise the output of the CNC machine, the cutter will have to travel faster around the work-piece. As this study is intended to be a meaningful work on modern CNC technologies, it is worthwhile mentioning some new tooling technology that is being used in Europe. This technology is covered in the chapter on Future Technologies.
2.10.3 Basic Router bits compared

Burkin (1999) reviewed 17 brands of basic router bits for Fine Woodworking magazine. The tests were performed on straight bits with two cutting edges. The bits were unused, half-inch diameter and carbide-tipped. A CNC router was used to test the bits cutting mid-way through the material in order that the location of each cut and tool could be noted. The machining was done by a qualified cabinet shop. The material used was melamine-coated particle board. Burkin counted the number of chips in the grooves made by the cutters, adding the chips in the first 25 feet to the chips in the last 25 feet of each cutter's test to achieve an average number to compare the cutting bits. Burkin was able to rank the 17 bits in order from best to worse for clean cutting. High-performing tools are essential in high-volume and high-quality CNC production. The results of Burkin's trials are relevant as they identify that not all available tooling is of the same quality or will perform to the same standard in terms of both quality and longevity.
2.11 CNC Software.

CAD-CAM is a more recent development of the CNC technologies. Much of this development takes place due to the demands of the engineering industry but this progress is also relevant to the woodworking sector. CAD-CAM is the integration of the CAD (design or drafting) process with the CAM (manufacture) of the component. A suitable CAD-CAM system should be considered essential when purchasing computerised machinery. In fact, CAD-CAM software is often considered an option and this limits the potential of CNC equipment.

2.11.1 CAD (computer aided design)

CAD systems are generally classified as either 2 or 3 dimensional. A 2D system draws lines on an XY plane with no height values. A 3D system allows the user to define elements in three-dimensional space, allowing the creation of 3D wireframe models (two and a half dimension), with solid modelling (3 dimension) capabilities. A chair seat designed on a CAD program is shown in Figure 14.

![Figure 14 Chair seat designed on CAD](image-url)
CAD programs are object based graphics applications and interpret screen images as mathematical constructions that can be readily manipulated. For instance, a drawing entity (line or arc) is described as “a line from a start XY position to an end XY position in a certain colour and on a certain layer”. This is different to painting and photographic software programs such as the paintbrush program supplied with “windows” software. These paintbrush programs generate bitmapped images that use coloured dots much like the pixels on a TV screen. Some bitmapped file types are bmp, pcx, tiff and jpg.

While all CAD systems use object oriented data type, the file format can differ. The file format is how the information is encoded, and for compatibility between different CAD programs, this encoding is often provided in a neutral format, such as IGES, HPGL (Hewlett Packard graphics language) and the most popular DXF (originated by AutoCAD, stands for Data eXchange Format). A CAD-CAM program which is unable to produce one of these file types will not be able to read files from another program, and manufacturer’s will not be able to send work to a customer who has a different CAD software program.

2.11.2 CAM (Computer aided manufacturing)

CAM programs take the CAD drawing to the final stage to plan, manage and control the operations of the factory through direct interface with CNC machinery. CAD-CAM is today mainly applied through individual machines controlled by task specific software, but the possibility is there to go beyond this narrow application and to control the whole manufacturing process. This is referred to as computer aided manufacturing. With this technology, the process is controlled from the part design stage through the machining of parts on the pressure beam saw; edge bander and CNC processing centre. Controlling parts through the entire production process is referred to as “CIM” (computer integrated manufacturing). The chair seat with tool paths applied is shown in Figure 15.
In the CAM (machining) process, the product parts are processed into machine language that is transferred to CNC machinery as coded tool path information and this is covered previously. These codes control the tools and movement of the equipment that in turn produces the components, usually to a required accuracy of at least one hundredth of a millimetre. There is minimal operator input at the machine so semi-skilled persons can be used to load the parts onto the machine table and stack them when the process is complete. This eliminates mistakes, and speeds up the setting up of the equipment for a production run. This time is often reduced from hours to minutes, and in some cases even seconds. The toy motorcycle shown in Figure 16 was designed on CAD during this study with the various elements split between different layers but on the same CAD drawing. Each layer was then transferred to the CNC machine for processing. If the parts were cut on a machine with a flat table the entire list of parts could be processed from one sheet of material. If the parts were cut on a
machine with pods to hold individual parts, each part would need to be loaded separately.

2.11.3 CAD-CAM Applications

Currently, the major use of CAD-CAM in Australia is in the kitchen and cabinet manufacturing industry. Here CAD can be initially used as a sales tool, referred to as a “front-end” system. Views from any angle complete with light and shade, reflections, kitchen utensils and furniture, and even views through open windows are available. Recent developments include a virtual-reality walk-through. A front-end system will produce photo realistic pictures and cutting lists, but may not be able to produce any NC machine codes. After the design has been established, the manufacturer is able to view a plan drawing of all the cabinets in the plan shown in Figure 17.
A front-end system can be upgraded to a manufacturing aid with the use of an optimizing program. An optimizer will produce detailed cutting lists of all parts required for the job. In addition, a waste percentage, amount of edging required, time to complete and production costs may also be calculated. The optimized cutting patterns can be downloaded to the CNC machine for immediate processing. Optimizing software needs to be purchased from an industry supplier, and is not usually available as a retail product. As the optimizer is an aid to manufacturing, it is in fact a CAM program.

The optimiser output (Figure 18) can be set for maximum part recovery, which may require the sheet to be turned during cutting if a panel saw is used. The recovery can alternatively be set for the fastest possible cutting speed, where maximum recovery per sheet is ignored. The costs are accurately established before production begins.
After the parts have been cut, the CNC machining information can be applied through a CAD-CAM program supplied by the machine manufacturer. These are true CAD-CAM applications, howbeit machine specific. This means they were designed with a specific machine brand in mind. These programs are also mainly focused on manufactured board. The parts are drawn on the computer, and the machining processes applied. These processes include drilling, routing and sawing processes, and on recent machinery include edge banding and sanding. The optimised machine codes are then sent to the machining centre, where modifications can be made. Usually, however, the programs are ready to run and need little if any modification. Figure 19 shows doors and carcase panels being machined in MDF from a CAD-CAM program.
For parts manufactured in solid wood, such as solid timber furniture, CAD software programs can be used to produce three-dimensional drawings. A tool path is then generated which is converted into machine code. This process is called "post processing". A CAD drawing from this software can be post processed to run on any CNC machine. The most common standard format is the G-code machine language, a universal set of standard linear and circular motion commands that are modified during the post process stage to suit the specific tooling requirements of the machine.

In addition, digitizing or scanning can develop machine code. A digitizer is an electronic tablet available in various standard thesis sizes. The part drawing is placed on the tablet and a stylus or puck is used to identify key points on the drawing. Digitizing is a quick method of programming parts from a sample
drawing or trace. Digitizing is rarely used in the wood working industry except for novelty items.

Scanning can be performed with hand held or flatbed scanners, the resulting bitmap image converted into a vector (CAD) image, then edited to smooth out crooked lines and eliminate unwanted ones. Scanning may require a fair amount of time-consuming editing to “clean up” the image. Scanners are used extensively in the sign-writing industry where machine code is sent to flatbed routers that use drag-knives to cut lettering.

A further element of the CAD-CAM process is the ability to schedule the production. This can be done with a job-scheduling program. A calendar shows the schedule for each work centre (machine) in the factory and a summary of the hours required for each job. These programs are difficult to get working properly as they do not allow for any problems or unforeseen circumstances that do arise from time to time. Generally though, the people who use them say that they give a target to work towards, and can be an efficient production aid.

In a mass production situation, the cost of planning, design and setting up for each process would seem to be a small consideration. However, today’s production requirements call for small runs of consistent quality at short notice. Only by employing the benefits of CAD-CAM are companies able to work towards these needs.

2.12 System 32

In the flat board sector, it is possible to manufacture a complete cabinet in less than ten minutes. This has been made possible by CAD-CAM software and CNC controlled machinery, and an extensive range of hardware designed for rapid assembly. These methods and machines are all based around a 32mm spacing of working units, usually drill bits, and utilise a range of fixings known as system 32. System 32 or “knock down” fixing can be used in kitchen, office, commercial and domestic furniture.
The first attempt at mechanical joining of furniture was developed in the mid 1920’s. In 1957 the first patent of what could be called the father of the concealed hinge was granted to Arturo Salice, of Como, Italy. Over the years, manufacturers of machinery have worked together with hardware suppliers to develop a manufacturing system that was simple to achieve, quick to produce and was able to accommodate many different hardware products.

Much of the furniture manufactured around the world today uses manufactured board as the raw material. Even traditional solid timber users are gradually introducing veneered board into their products. These cuts down on costs and produce a more stable item of furniture, especially on wider components such as tops and sides of cabinets where solid timber used in these situations has a tendency to warp and bend. Products such as particleboard, medium density fibre-board (MDF) and to a lesser extent, plywood are all widely used throughout the world. These products readily lend themselves to construction methods based on system 32 commercial mechanical fixings.

2.12.1 Basic Principles

The system 32 came about as a result of improvements in materials and machinery. Where large amounts of holes are required, as is the case when panels are joined together, multi-drilling machinery is necessary. A hardware system based on predetermined drill spacing’s is essential in allowing quick fitting and assembly of the mechanical fittings.

The principle of “just in time” whereby only the products ordered are produced has enabled furniture manufacturers to cut down on overheads such as storage areas and large stocks of panels. This system is based on the rapid set-up and processing times provided by system 32. With system 32, it is possible to drill all panels with the same drilling pattern, and then to add the hardware required for the particular panel’s use. Shelves can be positioned at any height, doors can be fitted as left or right opening, and drawer runners can be added. All this with the one set of 32mm spaced holes. In addition, a wide range of accessories, especially for kitchen and office use, can be added with only a screwdriver.
When working with 32mm hole lines manufacturers should be aware that all holes will be 5mm in diameter and every hole in the row must be divisible by 32mm. The distance of the first hole from the top of the panel will usually be the same as the last hole from the bottom of the panel. Typically, the distance from the front of the carcase to the first line of 32mm spaced holes will be 37mm, and this will be the distance that drawer runners and door hinge mounting plates are manufactured to. With system 32, all holes for mounting of hardware are produced in multiples of 32mm. Holes spaced at 64, 96 and 128mm are common with drawer runners, and all true system 32 fittings will have a 32mm hole spacing. Dowel drillings should be central in shelves and top and bottom panels.

### 2.12.2 Panel Joining

The range of system 32 panel fixing is divided into three broad groups. These are concealed, surface and flush fitting. Concealed fittings are a knock down type and are the most popular. These fittings are available in plastic and metal, and all use a metal stud, or “dowel” and a screwdriver operated CAM to lock the parts together. Recent developments by several companies have resulted in tool free assembly of semi-concealed fittings. Concealed fittings require sophisticated machinery to drill accurate holes in the ends of panels, as well as the surface.

Surface fittings are similar to the concealed variety, but are as the name implies, mounted on the surface of the boards. They are cheaper than the concealed fittings, and have the advantage that they can be fitted with very little machining. Flush fitting devices rely on a press stud action, and are of a permanent nature. A ridged insert fitted into a pre-drilled hole on one component is brought into contact with a metal dowel fitted into the second part. The metal dowel is able to be pressed into the ridged metal spring, but cannot be removed. Very accurate machining is required, and the product cannot be “flat packed”.

Concealed hinges can loosely be described as a system 32 product, but now most brands have different hole spacings for the hinge, which requires one 35mm hole and two 10mm holes for the screw plugs. Manufacturers with CNC boring machinery can bore holes for accurate assembly within seconds. A recent
development in knock down or panel hinges is the ability to assemble without the aid of a screwdriver. The tool free hinges and mounting plates can be locked in place and dismounted by operating a lever, which usually doubles as a cover. They are more expensive, but doors can now be shipped without hinges and installed on site, without any damage caused by protruding door hinges.

2.13 Nested Based Manufacturing

Nested based manufacturing (or NBM) could be described as the most significant (woodworking) technical development of the last fifteen years. NBM was developed by the German Benz Company before World War 2 for producing economical automobile parts from rolled steel. In the furniture industry it was widely accepted first in the United States some twenty years or so and has been popular in Australia for almost as long. Nesting is a growing trend for smaller woodworking shops. More than seventy five percent of CNC machines sold in Australia over the last ten years have been nesting machines and this is confirmed by principals of three major CNC machinery suppliers. This number is also a reflection on the number of companies working in the Kitchen and Bathroom sector.

The biggest advantage for NBM manufacturing is the software. With NBM the operator is less of a programmer than a cabinet designer. With traditional manufacture the operator could be inputting the data for individual panels. With NBM the operator gets a file from the kitchen design or furniture design software that is run through a nesting program. This file is then sent to the machine and the work proceeds immediately. A by-product of the new software is the ability to cost the individual parts and even the entire kitchen, thereby ensuring that the process is a profitable one. As entire kitchens are the product of the NBM manufacturing philosophy, it can be argued that in this case, batch size of one is a reality. A nested job for flat panel furniture is shown in Figure 20.
The cutter (several if the machine has a tool change) runs around the entire panel, inserting holes for connectors, running rebates and grooves, and finally, cutting out the panels including the notch for the toe-kick. This final operation is usually done in two passes (but can be done in one). The first can be quite quick and usually leaves half a millimetre on the edge of the panel to remove on the last pass. It is also to a depth of within a millimetre of the sacrificial sheet. This sheet is a thin MDF “waste-board” on which the whiteboard sits. This twin-cut operation is often necessary to avoid smaller pieces moving around at the end of the cut. Larger pieces are generally stable and may not require this first cut. This cut is often referred to as “onion-skinning.” After this, the cutter runs around the pieces one more time to separate the pieces and provide the final sizing cut. This final pass also assists in removing most of the dust generated by the first cut.

Figure 20 Nested pattern for furniture
2.13.1 The Benefits of NBM

The most obvious benefit of the NBM system is reduced machine cost. A Nested-Based system does not require a Beam Saw and this in itself will cost from (around) $120,000 to over $200,000 for a system incorporating materials handling capabilities. Added to this cost will be the considerable floor space required not only for the Beam Saw to sit in, but for the stacks of parts generated and awaiting further processing on the CNC machine. The production time for a cell-based system is almost universally agreed to be longer. Given that the equipment is running as close to a full shift as possible, manufacturers also have the cost of an additional operator to take into account.

Nested-based manufacturing becomes a better option when run volumes are lower. If manufacturers are cutting two sheets or less on the Beam Saw, then a nested-based system starts to become more agreeable. Today’s high machine speeds and excellent tooling solutions means that in most cases production costs for single-sheet jobs are a lot less than for cell-based manufacture. A major consideration with NBM is the ability to predict costs. If the costs are based on the software and machining time of one machine it is a much easier calculation that attempting to add up the cutting times of a kitchen from four or more sheets on a beam saw coupled with individual times for multiple parts machined on a CNC machine.

Training is another consideration with the NBM process. The more machines a Company uses the more mistakes can be made by inexperienced operators. A worker can cut a lot of board in an eight hour shift and a small mistake could cost thousands of dollars in stock and re-work. Low skill levels can be overcome to a degree with NBM. As only one major machine is being used and the program invariably comes from a software program, the operator only needs to know how to load the program, start the machine and clear away the parts and waste. On a cell-based system the operator is calling up individual programs so the training requirement is greater.
2.13.2 When is NBM right for Manufacturing?

A Melbourne-based kitchen manufacturer makes two to five kitchens a week using a cell-based manufacturing system and up to ten factory personnel. Another manufacturer makes ten kitchens a month using a NBM system but is a one-man shop. Such is the power of NBM that he can set the machine for a five to nine minute run and use this time to edge and assemble his cabinets. In fact, claims of up to eight times the output have been made. Manufacturing production costs are machine plus labour plus tooling plus handling plus assembly. The NBM solution reduces machine costs, labour costs and handling costs.

One problem with NBM is that the company is limited to the number of sheets they can process on their nested-based machine. As the company grows, they either install another nested-based machine or supplement it with a panel saw. The larger the table, the more efficient the NBM operation will be. If a kitchen takes 100 square metres of material, using 2.4 X 1.2 metre sheets they will nest 35 sheets; with 3.6 X 1.8 metre sheets they will nest 16 sheets. With an average sheet change of 5 minutes, including spoil-board cleaning, the saving is one and a half hours for this kitchen using larger sheet sizes.

In a post on a U.S. woodworking forum a manufacturer claimed to have run a job at twice the “recommended” feed speed of his tooling. His “saving” over six minutes was only twelve seconds or three percent. This is due to the machine needing to “ramp” up to top speed and then to decelerate before rounding a corner. It was found that the machine only operated at its full speed for less than 10% of the total cutting time. In NBM, speed may not be everything.

When considering a cell based system over a nested based system, the final decision is generally based on production requirements (volume) available floor space, financial resources, employee skills and finally, the need for flexibility. Generally speaking, a flexible, low-volume manufacturer, or a manufacturer with a varied parts production such as in specialised design kitchens would be well-placed to install a nested based system.
If a Company uses 15 to 80 sheets of material per day and the parts do not require extensive horizontal boring, consider a Nested-Based manufacturing solution. If a Company uses more than 80 sheets per day and has an accurate panel-sizing solution such as a CNC beam saw and a requirement for extensive horizontal boring, consider a Cell-based manufacturing solution.

2.13.3 NBM Levels

There are three basic levels to Nested-Based work cells. The first level is a CNC router controlled by a program where “nests” of parts are produced by a CAD/CAM system. This can be a generic drawing program such as AutoCAD, or dedicated design programs. The software should be capable of generating part lists for all the cabinets in the design. Automated nesting software can be a worthwhile option in reducing time in developing nests of components.

In a more advanced level the design of the part layout is enhanced with a parametric function. This means that parts are designed with a set of “rules”. These rules set the position of holes and routings relevant to the dimensions of the piece. Manufacturers can cut a cabinet door with the same tool-path in several different widths and heights.

The fully automated level sees a software package extracting all of the files needed for the entire job directly from third-party cabinet software. It then nests the parts and generates all the programs for the sheets of material to be processed. At any level, the nesting software is vitally important to the success of the NBM installation. The software used is possibly more important than the machine.

2.13.4 NBM issues

Some considerations in the NBM process are dust, waste and hold-down of parts. A large diameter cutter will produce a lot of sawdust and may reduce the yield from the sheet. When the parts are cut, the seal between the sheet and the sacrificial board is lessened. As a result, the most common tool for nested based manufacturing is a 9.5mm compression cutter. This cutter is designed to cut in a
downward motion and actually packs the sawdust in the space between the parts that have just been cut to preserve the suction. The problem with this is that when the nest has been cut, there is a lot of sawdust to remove before the next sheet can be loaded and this takes time. To eliminate this, some machines are fitted with blowers that direct a jet of air into the cut to remove the sawdust. A typical compression cutter will cost $60 or so and is often discarded when it dulls.

Holding the parts onto the table is more difficult if manufacturer's cut smaller parts. As most users manufacture kitchens this is usually not an issue. For a machine with a standard 2.4 by 1.2 metre table a suction pump of 250 cubic metres per hour is sufficient. A 3.6 by 1.8 metre table will need a pump of 500 cubic metres per hour. The trend in Europe is to conserve energy so the pump there is likely to be a type that uses as little power as possible and operates at high efficiency. This technology costs more up-front and will take some time to become popular here. The trend in Australia is to have more, smaller pumps with a table divided into sections. If the sheet size is smaller, one pump can be turned off, saving energy.

2.13.5 Applications of Nested-Based Manufacturing

The case for nested based manufacturing is fewer and lower-cost equipment, less waste and speed of production. The nesting software is simple to learn and easy to apply. Mistakes that occur with multiple machining operations can be eliminated. Where skilled workers are difficult to source, the NBM system has some distinct advantages. One machine, one employee and one sheet of material. Import the parts, run the nesting software, download to the machine and within a minute or two the manufacturer can be machining parts. Depending on the number of parts on the table (the nest) the cycle time can be as little as five minutes. Provided all the machining can be done with vertically mounted tools the NBM process is an attractive manufacturing solution. Most experts agree that NBM is ideally suited to small and medium-scale businesses.

Some claims have been made about nesting that the author disputes. One machine manufacturer claimed that you could purchase material with surface
defects (seconds) and nest around the defects. The author would suggest that the time to do this would negate all the benefits of the nesting installation. Another suggested that the operator could use a horizontal boring machine to drill horizontal holes while the machine ran another nesting operation. Given that the nest would almost certainly be composed of different sized panels, the author does not believe an operator would have the time to set up a horizontal drill several times and run perhaps a dozen cycles in the five minute cycle time claimed by the NBM supporters.

Cutting small parts used to be an issue, they simply could not be held effectively. Modern software has overcome this by placing small parts in the middle of the nest and cutting the small parts first. Larger vacuum pumps and sectioned tables have also helped. Automated in-feed and out-feed systems can reduce the loading time by many minutes, but the cost of the installation has almost certainly jumped to around two hundred thousand dollars. However at the entry level, NBM has effectively evened the playing field between small and large manufacturers. With larger manufacturers going offshore, and large amounts of cheap imported goods flowing into the country, an industry capable of quickly responding to custom installations for domestic need is essential.

2.13.6 The Cellular System.

NBM manufacturing using CNC machinery is a direct competitor to the “cellular” manufacturing system. Cellular manufacturing is the traditional method of working where a CNC Beam Saw, Edge Bander and CNC Processing Centre are grouped in a manufacturing “cell” to manufacture components. The benefits of a cellular system are that high volumes of similar parts can be cut on a Beam Saw much more economically than singly on a CNC NBM machine. Four or more sheets can be cut within a few minutes. For high-volume kitchen, bathroom and office furniture manufacture; a cell-based manufacturing system would appear to be the most beneficial and economical form of manufacturing parts.

Another benefit to cellular manufacturing is that larger enterprises have the advantage of using custom material sizes to avoid waste. They use lean
manufacturing that maximizes throughput from individual operations. A large office furniture manufacturer in Germany (Werndl Steelcase) cuts over-size sheets using a nested based system but the rest of the factory, using over a dozen CNC machines, uses a cell-based approach. The reason is the company does a lot of custom installations that does not suit NBM.

Paul Hix, product manager, Altendorf America (machinery supplier) says, "There is a market for nested manufacturing just as there is a market for a work cell environment. It all depends upon the volume, numbers of employees, how technically savvy the people are and the amount of money they want to spend. When you look at nesting, it's very heavily-laden in software and programming and that's not right for everybody. Plus, if you look at nesting, it may not be the right solution for smaller shops that want to have a versatile set up from the standpoint of doing anything from restoration work to architectural millwork all the way through store fixtures. If that's their scope, nesting is not the right solution."

2.13.7 Cell Based Manufacturing

The case for cell-based manufacturing is flexibility and volume. Manufacturers have almost unlimited possibilities of different drill bits, grooving saws, as well as routing, shaping and angle-processing functions. Horizontal processing is also available for drilling dowel and other holes for mechanical connectors. If material clamping is an issue or they work mostly in solid wood, the cell-based system is ideal. In addition, a panel (beam) saw is capable of cutting four sheets at once (book cutting) and producing a large amount of material in a short time. Labour is a greater cost than material, and some waste at the beam saw is more than offset by the increase in production at this stage. NBM supporters say that the high cost of a beam saw (or panel saw) can be avoided, but almost all cabinet shops have a saw of some kind to cut wood and other materials.

NBM has been slower to gain acceptance in Europe due to the size of the manufacturing applications. In Europe it is not uncommon for a company to buy pre-cut panels from another. In Europe, volume is important due to the size of the market. A very large manufacturer of cabinets, located near Rosenheim
(Germany) is the Werndl Steelcase Company. They do about a million dollars’ worth of business a week in mostly panel product. They use a nested based router to cut parts from very large sheets, but the rest of the machining is done with rail-type CNC machining centres. One reason is that the company manufactures components in a variety of different materials including solid wood. A wholly-NBM system would not be effective in handling solid wood components.

For larger manufacturers, or smaller ones with a uniform range of parts, a cell-based system could be more effective. A beam saw cutting up to four sheets at a time in a “book” could feed two machining centres where the programs for the standard parts are pre-determined and can be called up within seconds. Little tool changing is required for cabinet work (kitchens, shop-fronts and office furniture) so the change over time is minimal. The use of parametrics enables variations to the components to be achieved in seconds. Another consideration is that with a NBM system the company is limited in its production and unable to grow into other areas of production.

NBM manufacturers may use a process called “onion-skinning.” This involves rough cutting around the component and leaving half a millimetre of material at the bottom of the cut. The finishing cutter is then sent around the parts a second time, making the final sizing cut and cutting through to the spoil board. This process doubles the actual machining time required by the system. With a machining centre a single cut is all that is required to size the panel, followed by vertical and horizontal borings, all without the necessity of a tool change.

2.14 Future Technology.

Homag (machinery), Leitz (tooling), Leuco (tooling), Benz (spindle development), IFW (University Stuttgart), FH Rosenheim (University Rosenheim), Reichert Holztechnik (manufacturing trials) and Wossner (manufacturing trials) have completed a four-year government funded program into high-speed cutting using CNC machines. Current research includes spindle development, safety, and the removal of waste (chip flow) at high cutting speeds. The German ministry for education, development and research funds the program. When this technology
becomes available in Australia, production of components on CNC machinery can be doubled. This chapter covers high-speed cutting and the benefits to CNC users.

The term “HSC processing” (high speed cutting) originates from the metalworking sector, and refers to the cutting or machining of materials at enhanced (higher) cutting speeds. The mechanical engineering requirements for HSC processing are a high degree of rigidity in the machine frame, improved axes drives for greater response accuracy, high spindle speed and tools designed for high-speed rotation. Current wood working CNC machine spindle speeds are supplied in the order of 18,000rpm to 24,000rpm with 18,000rpm being the most common speed. Improvements in the edge quality of wood and furniture components can be achieved by increasing the cutting speed of the tool. The cutting speed refers to the actual speed of the tool edge and this is often referred to as “fly” or “peripheral speed”. It is not the revolutions per minute of the spindle although a higher RPM will achieve a higher cutting speed.

It is possible to increase the cutting speed of tools by increasing the tool diameter but unfortunately the greater the tool diameter the greater the possibility of imbalance. Increasing tool diameter also means that more teeth are required, as the tooth progression (distance between each cutting tooth) will change. In the woodworking sector today, cutting speeds of up to 80 metres per second (m/sec) are achieved when trimming with large diameter profile tools. The blue dashed line on Figure 21 indicates this. At 18,000rpm a tool of 83mm diameter will produce an optimum cutting speed of 80m/sec. It is evident that at 18,000rpm the optimal diameter of profile tools used on existing CNC machines is in the range of 80mm to 90mm diameter. As the tool diameter is restricted by limits in terms of both geometry and cutting technology, the potential of HSC processing lies in cutting processes using small diameter tools and higher spindle speeds.

The optimum wood cutting speed range of routing tools is 50 to 80 metres per second and small diameter tools are unable to achieve even the lesser speed. A 25mm cylindrical router cutter has a peripheral cutting speed of only 23 metres
per second at 18,000rpm, or less than half that recommended. It is in the area of small diameter tools that gains in quality and productivity due to greater spindle speeds is most apparent. To achieve optimum performance it is necessary to lift spindle speeds to between 30,000 and 40,000rpm. New-technology “Tribos” and “Thermogrip” type chucks as shown in Figure 11 are suitable for HSC. For HSC cutting, Hydro chucks are unsuitable as the fluid deforms at speeds in excess of 24,000rpm and the tool can slip.

The benefits of HSC are that higher RPM brings the cutting speed to an optimum level and higher feed speeds can be used to reduce the cutting time, increasing material output. Put another way, if the rotational speed of the spindle is increased, it is possible to also increase the feed rate while retaining a constant tooth progression. This reduces machining time and so results in shorter
production times per piece. Some examples from German research are a diamond cutter of 25mm diameter cutting at 15,000rpm and achieving up to 10 metres per minute feed speed on a veneered particleboard tabletop. Using HSC technology, a smaller 20mm diamond tool rotating at 30,000rpm achieved a feed speed of 30 metres per minute, or three times the production. In another trial, the feed speed for MDF bench tops was increased from 8 metres per minute to 40 m/min. A door manufacturer (Reichert) using a 120mm diameter hydro tool to profile 20mm thick maple doors achieved up to 9 m/min at 13,000rpm (the maximum permissible safe rotational speed) but doubled the output with a 44mm diameter tool spinning at 30,000rpm.

The higher kinetic energy of HSC cutting presents an increased risk if tools were to break. Human error in installing the wrong tool and accelerating a large tool to very high speeds will also be a serious risk. Expensive CNC tool management systems using microchips embedded in the tool itself is currently the only sure way of preventing this. Future developments will see torque momentum sensors on the machine spindle. The integration of the machine into the operating environment will be an added challenge. Present-day processes can be slowed when the CNC machine is used to process the majority of components and then becomes a bottle-neck. In a HSC situation the circumstances will be reversed as the machine produces far more than the rest of the factory is capable of.
3. Case Study - Carl Hansen and Son.

Australia is isolated geographically from the major furniture producers in the rest of the World. China is our closest major producer but it is well-known that in the main, Chinese manufacturers produce in volume and this is not relevant to this study. Furniture manufacturers that produce in similar quantities to Australia can usually be found in Europe where there is a mix of very large, medium and small enterprises. The majority of Australian-used wood working machinery also originates in Europe along with a good percentage of new technology. It is a fact that the three largest suppliers of CNC equipment for the wood working trades are located in Germany and Italy. For the purpose of this work, a medium size manufacturer using best practice lean production was visited to see how good quality furniture is produced in small batches for domestic and export markets.

Carl Hansen specialises in classic design chairs by Hans J. Wegner. Carl Hansen has been making Wegner’s designs since 1949 when the wishbone chair (CH-24) went into production with a woven fibre seat shown in Figure 22. Other designs include the CH-07 (shell chair) a three-legged chair designed in 1963 featuring a lacquered bent plywood frame with wool seat elements. The “shell” chair retails for around AUD$2,000 each. The stackable CH-20 (“elbow chair”-1956) is one of the most difficult chairs to manufacture and this has been achieved by the use of high-technology. Carl Hansen also produces a number of other classic Wegner chair and table designs exhibited at The Museum of Modern Art in New York. Carl Hansen is a company built on quality, technology, relationships and design.
Figure 22 CH24 Wishbone chair
3.1 The Factory

The company Carl Hansen and Son is located in Aarup near Odense in Central Denmark and is 100 years old. The new 6,000 square metre complex was built to create an environment planned to maintain traditional craftsmanship and modern technology. Production is entirely Hans Wegner’s designs and is sold in North America, Japan and throughout Europe. While the present factory employs the latest technology, products are still made with attention to detail and traditional construction methods. Oak, Cherry and Walnut timbers are delivered three times a day to minimize inventory. Delivery of wood daily is unheard of in Australia. The wood is steam bent as required, or machined in four automatic copy lathes. All reject timbers are returned to the supplier for credit, eliminating scrap. Returning wood to the supplier is also unheard of in Australia. Carl Hansen uses five axes CNC machines to shape some complex components because low-technology countries are unable to compete against the repeatability and consistent quality.

Figure 23 CH20 Chairs
The furniture designs are also very difficult to copy. As an instance, the CH20 chair side, back and front rails (Figure 23) are curved and meet at the legs. Designed in 1956, it was believed to be too difficult to manufacture economically until new technology was available.

No mechanical fixing is used on the product and all assembly is done with traditional cabinet making joints such as dowels and Mortice and Tenon’s. Some species (especially Oak) often move during the (glue) drying process so the assemblies are held in custom made clamps until dry (Figure 24). A significant part of the process is in sanding the product and some of this work is done with computerised robots on a twenty-four hour a day schedule. Robots are becoming more common in the European furniture industry and Denmark is a World leader in robotic technologies through the Odense University College of Engineering’s “Robocluster”.

Apart from sanding, the finishing of the product is often outsourced as this process is very time-consuming. Before sanding, all the parts are soaked in a solution of soap and water to raise the grain, resulting in a glossy, smooth finish that is a characteristic of the product. The end of the process is the weaving hall. Forty weavers weave only eight chairs a day to ensure consistent quality.

In 2005, Carl Hansen produced four times the number of chairs they made four years previously due to CNC manufacture. The high cost of the product makes efficiency more important and plenty of time is devoted eliminating production problems. Engineers are employed to look at minor changes to the manufacturing process in a continuous improvement schedule. New technology is used to allow the company to expand, lowering costs and maintaining quality.

What can be learned from this case study is that quality product inclusive of traditional wood joining methods, can be successfully made on CNC machinery. Raw material is delivered daily and small batch sizes of 20 chairs are the norm. Parts are not machined on a table where all the parts are machined at the one time. Parts are produced individually and either clamped on the table or held in a jig designed for just that one part. It seems that Carl Hansen has a very close
relationship with their material (wood) supplier and pays a premium for this service that includes the return of defective parts. It is unlikely that an Australian manufacturer will pay more for raw materials than required but looking past the initial cost, the manufacturer will see the benefits of first-grade material always being available. This avoids the cost of re-work so the actual planned CNC machining times can be met and no future work is held up. It is interesting to note that Carl Hansen only produces chairs and a few table designs. Australian manufacturers produce a much larger range of furniture items that inhibit easy change overs (setups) and smooth production flow.

Figure 24 Custom clamps hold frames to dry
4. Results of Investigation and Discussion.

This chapter provides the results and discussion from industry visits, consultation with training and machinery supply professionals and literature review.

4.1 Integrating CNC into the Furniture Workshop

When first integrating CNC machinery into a workshop it takes some degree of skill to know what can be produced and how quickly this can be achieved. The workshop needs to be set up so that the CNC machine does not become a bottleneck, with stock-piles of components waiting to be processed. Issues such as the location of the machine, what will be produced, the tools and equipment required, who will operate the machine and the flow of work all need to be addressed if the CNC machine is to deliver on its designed production capacity.

On a more complex level, several CNC machines could be used to form a manufacturing “cell” and here there are several variants to consider. The path of least resistance is to get all the equipment from one supplier. Here there is a single company to deal with where a single company will solve all the problems. Most of the operational issues should have been eliminated because the software has been written to suit a range of machines that are under the control of the one supplier. The drawback could be that the suppliers mainly manufacture machines; the software is a by-product that may not offer the features available from a dedicated software house.

4.1.1 Material Flow in CNC Operations

The wood working industries in Australia continue to face competition from Countries with more favorable labor costs. This disadvantage is not going to change. To overcome this disadvantage it's vital for manufacturers to look at all of the costs of manufacturing to ensure the product is being produced at the most competitive price. One of the major hidden costs of manufacturing is time.

The cost of machinery; raw materials; electricity; rent; labor and overheads can be manipulated slightly but the fact is that most Companies are settled in a
specific location; have existing equipment; produce a traditional product with a static workforce and buy materials from established suppliers at possibly the best prices they can negotiate already. Given this, the only real impact on the cost of manufacturing is the time it takes to process the raw materials into the finished product.

The issue here is not about time and motion. Time and motion as a principle is not popular with workers and unions and the principle itself lacks scientific substance. Time and motion is about what a worker actually does and in a wood working factory this question is difficult to answer. However, the principle of rationalizing production is worthwhile and every effort should be made to ensure that the product passes through the factory in the most effective and efficient way possible. A production engineer would have the knowledge to organize the factory for the most efficient production but the author is yet to see a fully paid production engineer in a wood working factory in Australia.

It is of little concern what a Company makes or what equipment they have. The Company could be making pallets, kitchen cabinets or bedroom furniture. The principle of organizing what is available for the most efficient production will be the same. The goal is to save time because time is money. The longer it takes to get the product through the factory, the more power is used, the more overheads will need to be paid, the more the labor costs will be and the more the Company will be carrying the cost of the raw material. If it takes a week to get the product made, the manufacturer will get paid based on that. If it takes two weeks it will take twice as long to get the material costs back. It's not as simplistic as that but the author believes the principle is sound. The longer the part is in the factory, the longer it will be to get a return on the outlay costs of materials, equipment, labor and overheads.

Most furniture factories evolve. They start with a table saw; add an edge bander and possibly a few static machines. Management moves the assembly around to fit the machinery in and then possibly add a CNC machine. All the time the feeling is that the production is getting better because there is more and better
equipment. But the question is, is this really the case? Perhaps the machines are all in the wrong place. Maybe they've been put where they are because the space was available, or the Company couldn't afford to run too much extraction to a further location. There is anecdotal evidence to suggest that CNC machinery was placed close to a supervisor's office so they could keep "an eye" on the operator.

What the Company needs to do is to stop and take the time to have a real look at what's going on. A few hours standing in one place, watching the ebb and flow of the employees and the work-pieces will reveal the movement of materials and manpower within the factory. It is possible there is a lot of movement for very little result. Every time a piece of wood is moved, something must happen to it. Value must be added. It's why CNC machines are used; they have the ability to do multiple operations and reduce the amount of "waiting" time. Waiting time is the time when a component is waiting to be processed. Management will probably find a component sits around the factory far more than it should.

4.1.2 Manufacturing Cells

The equipment used in furniture manufacturing processes is worth possibly millions of dollars. Unless high volumes are being produced, devoting separate production lines to different products is not feasible. Factory production lines are run as mixed-product production lines. The layout of a manufacturing process either with or without a CNC machine is critical in reducing the waiting and transportation time between processes.

The preferred model for modern manufacturing is the cell-based concept. Wemmerlov (1986) states cellular manufacturing has recently begun to receive heightened attention World-wide. Cell-based manufacturing is part of lean manufacturing and takes advantage of the similarity of parts and common work processes. Any number of machines performing different tasks but collectively produce one finished product should be placed together to create functional layouts; or work cells. This vastly improves work-flow; provides workers with access to common tools and jigs; reduces waste and improves employees work
balance. It may be identified that the manufacturing cell needs less people to do the same job, or the same person can do two jobs at the same time.

As an example, CNC machines should be close together. This sounds simple enough, but what the Company should be trying to do is to centralize the tools, jigs, programs and CNC personnel so they all work together. The employees can bounce ideas off each other and work together as a team, growing all the time. The layout of the equipment in the factory has a direct cost on material handling, the lead time of the product and the amount of work put through the cell. This affects the Company's productivity and profit margin. The cell layout is never specific but two solutions could be considered. The first is a U-shaped cell where the start and end of the process is at the same place in the factory. If the cell is CNC manufacturing, the saw might be followed by the edge bander and then the CNC machine, configured in a U-shape. If the product is solid wood panels, the cell may have a crosscut and rip saw followed by a surface planer, panel planer and maybe a spindle moulder or CNC machine. If it's in a U-shape the person cutting the raw timber can get instant information from the shaping station as to how many extra need to be cut because of rejects, because they will be standing close to each other.

The second solution would be a single or double line cell. A kitchen manufacturer may find a single line cell the best option while a furniture manufacturer may find that a line for panel production and parallel line for solid wood components would be the better solution. In my experience you should find that the length of a single line cell for panel production may include a saw, edge bander and CNC machine. The solid wood line cell would have crosscut and rip saws, planing machines, shaping and sanding machinery and will likely be as long as the panel line. If this is the case, both panel and solid wood products can be introduced to the assembly area in the same location. This would facilitate the matching of all parts to assembly diagrams and the needs of the assembly line. I have provided two very simple layouts as a starting point for ideas. Figure 25 shows the layout of a typical machine shop for a factory using traditional static wood working machines.
Figure 25 Plan for a wood working cell

Figure 26 shows one possible layout of CNC machinery to facilitate the flow of product where a CNC "Beam" saw is used to cut raw material. This plan suits a panel manufacturer. A manufacturer of solid wood products would need a variation of the two plans. Whatever plan is developed, the work should flow through the factory with little, if any backtracking. Product that stops forms a queue and queue's increase delays. If product stands in a queue for several days, it may be several days before the supervisor discovers it's not been machined correctly. If it goes onto the next machine or process within minutes, it is possible to pick up any manufacturing variations immediately. This could have a major impact on minimizing waste and re-work within the factory.
A kitchen manufacturer, for example, will know that for a basic floor-standing carcase there are four main components. The two sides are the same and are identical to almost all the other sides manufactured by that Company, except the overheads. The sides are cut to size, edged on the front and drilled for the adjustable or fixed shelves and the door hinge. They may also be drilled for the base, back and top rails. The back is cut to size and may be drilled for the sides. The base is cut to size, edged on the front and may be drilled for the sides. It may be that the base and back are not drilled at all and don't need to go anywhere near the CNC machine. Knowing the production method, the time it takes to process each part and the speed of the equipment can bring some clarity to the cell and allow management to make informed decisions as to the best layout. The working environment for a cell focused on batch size one is covered later in this document. Management can check on the "health" of the factory by using a "spaghetti" diagram to see the actual flow of work through the section or factory.
5. Experiments

5.1 Nesting, a Study

Furniture is manufactured from both sheet materials and solid wood. In fact, more veneered manufactured board is being used in furniture due to its directional stability and low cost compared to the same sections in solid wood. The processing of panel products such as plywood, MDF and particleboard with or without veneer is a major part of the industry. The perception that nesting is the faster and more cost effective option influences the purchase of equipment. Equipment purchased solely for nested based manufacturing directly affects what can be achieved using solid wood on that machine.

Batch size one could mean that all of the parts are gathered together and machined at the same time. Nesting is a current furniture process that machines all the manufactured board parts in a single machining cycle and the industry is familiar with this process. This process was studied to identify whether or not the machining of a group of parts together (batch size one) in manufactured board was more efficient than machining each part separately (current industry practice).

The benefits of NBM claimed by suppliers of CNC machinery in sales literature are more efficient utilisation of material by grouping; fewer equipment and less capital equipment costs; quicker production, less waste, higher quality, less inventory (materials in production) and more automated production. Additional benefits are that less-skilled employees can handle the production; there is less materials damage due to excessive handling and the elimination of custom-made jigs.

To assess the claims made by NBM manufacturing sales literature, a nesting company was visited and data taken from a common production run to establish a set of times for the job. Advance Cabinet Works in Melbourne use an SCM (Morbidelli) 3618 CNC nesting machine with automated feed equipment. Their production is mainly project-based so their cutting can be quite complex. For this
chapter the production at Advance was used as a basis for investigation and commentary.

During the study it was found that the feed speed used at Advance Cabinet Works is 11 metres a minute to accommodate the small diameter tools and the deep grooving cut required in the nesting production. In addition, the nesting cycle consists of two passes, the first to within 0.4mm of the table and the second cut to separate the parts. This "onion-skinning" operation is required because during the first pass, all of the dust is not removed from the cut and small parts may move on the vacuum table. The second pass gets rid of this waste. A sheet containing eight parts as shown in Figure 27 was machined. There was an end panel 1996 X 650; two doors 758 X 457 with eight holes each; and five drawer fronts 443 X 146 with two holes each. The total length of all edges was 16.04 metres by 2 cuts means that 32.08 lineal metres of board was cut. The job took 3 minutes and 32 seconds. At 11 metres a minute the machine is capable of 36 metres of cutting in this time so the remaining 44 seconds was spent positioning the cutter and drilling holes. The time to load and unload the sheet was 30 seconds more for a total of just over four minutes.

Castlereigh (Sydney) installed a **Felder Format 4 Profit H22** pod and rail machine and intend pursuing the cell-based (pod and rail CNC) manufacturing system for small batch sizes. On this machine the panels cannot be nested and are machined individually. Castlereigh use much bigger tools because they only have to trim the outside of the board a few millimetres. The feed speed was 25 metres per minute. It could go to 35 metres per minute and more with the right tools (cutters). In actual fact, the cutting speed at Castlereigh with a pod and rail machine was twice that of the feed speed at Advance Cabinet Works.
To see what the time difference between the nesting process at Advance and the single-part process at Castlereigh; the same job was run on the pod and rail machine at Holmesglen Institute at 11 and 25 metres a minute. For single part processing the sheets were first cut on a CNC beam saw and this took five minutes. Here then is the first issue with pod and rail and that is that for single sheet work; it takes too long to cut it on a saw. As a Beam Saw is required for pod and rail processing of cut parts, it is noted that the beam saw cutting time for our test pattern would have been one minute and 25 seconds per sheet if the height capacity of four sheets was utilised.

Processing the sawn parts singly on the CNC machine, the processing of the edge and holes on exactly the same pieces took a total 5 minutes and 5 seconds at the same (Advance cabinets) speed of 11 metres a minute. The time
differential is due to each piece being manually loaded but this allowed us to
determine that approximately 12 seconds is required to unload the finished part,
load the next piece onto the machine and start the cutting cycle.

At 25 metres a minute (Castlereigh time) the time was three minutes. The actual
processing time was 38.49 seconds (16.04 metres / 25m/min X 60 seconds) so
the remaining 2.4 minutes was spent loading and unloading panels and changing
tools between the routing and drilling cycles during each part. Allowing for the
calling up of the separate programs, we see that the claimed feed speeds of the
two manufacturers, the CNC machining time (counting the beam saw time)
favors the nesting scenario. The approximate machining times are: Nesting 11 m/min = 4 minutes; single part 11 m/min = 10 minutes; single part 25 m/min = 8 minutes.

If we did not re-cut the edges of these sawn panels on the CNC machine and
only applied the drilling cycle (the profiles are cut on the saw) the results are
completely different. In this scenario the machining time including loading of the
panels was three minutes and one second at 11 metres a minute because the
positioning speed of the machine cannot be increased. At 25 metres a minute the
time was one minute and 40 seconds for a total inclusive of sawing of six minutes
and 40 seconds. It can be seen from these figures that there were a few minutes
between cutting as a nest and single-part processing. The actual savings by
using the nested approach was determined by testing to be one minute and
twenty seconds for the entire cycle at 25 metres per minute. This will be
dependent on tooling that can achieve this feed speed.

However, we need to look closely at what the pod and rail machine has to offer.
This is flexibility leading to opportunities for further (design) work. The pod and
rail machine can be used for different kinds of work, e.g. solid timber, working
from different faces (sides of the work piece). This allows the manufacturer to
offer more products to his clients which others cannot produce. The ability to
machine the work pieces from the sides, allows for dowels and other kinds of
corner connections which increases the quality and accuracy when assembling
as the dowels locate the parts in every direction. This speeds up the labour intensive and costly assembly process. The loading and machining time in this case was slightly higher compared to the nesting machines, but the time saving in the assembly makes it profitable.

The lifetime of tooling is another benefit of the Pod and Rail machine as the cutters are working in a “cleaner” environment. The dust or chips can either be sucked in by the dust extraction or fall down between the panels. This minimizes the repeated cutting of the dust or chips laying in the already machined groove on the second NBM pass. Anecdotal evidence from industry suggests that only about 16% of the cabinet makers business is actual production of the physical product. If this is the case, the restriction to business by having machinery that may not be flexible is actually detrimental to the future of a Company.

Other things that must be considered is that nesting can be more complex than pod and rail/beam-saw machining and requires more control from the software as the software controls all of the program and not just one component. With nesting, workers can't touch any parts until the whole sheet is done. With a saw, the parts can be in the edge-bander as each comes off the saw. Nested manufacturing produces irregular shaped off-cuts. These increase waste and cause handling and storage issues. And finally, the fact is that if a Company is making kitchens (90% of the furniture industry in Victoria) and they buy-in their doors and drawer fronts, then 45% of the production is cabinet sides and these will possibly all be exactly the same (Figure 28). Floor kicks, top rails and shelves are all more efficiently cut on a panel saw. If this is the case and they get six from a standard 2.4 by 1.2 metre sheet, they may find that their nesting solution is saving them very little time and costing the opportunity to quote on jobs because they have streamlined themselves into a corner.
Figure 28 45% of cabinets are same-size sides
5.2 The use of Basic Router Bits for CNC processing

It is highly recommended that high-performing cutting tools be used on high-performance CNC machinery. However, low-cost tools are observed to be used to cut furniture parts on CNC machines. The effectiveness of low-cost; off-the-shelf cutting tools is investigated. Half-inch (1/2") shank bits were chosen because these are considered a professional standard. For this comparison and from least to most expensive were the T-cut Green-Line (Taiwan), the Carb-i-tool (Australia), the Jesada (USA) and the CMT (Italy). Half inch (12.7mm) bits generally carry a larger diameter tool than quarter inch shaft bits. They normally last longer and cut better than bits with quarter inch shanks as they are more rigid.

5.2.1 Tip Comparison

The generosity of the carbide tips on all four brands was evaluated in order to establish longevity of service. Measuring with a dial gauge Vernier caliper, the Carb-i-tool and T-cut bits had the thickest tips at 2.0mm. The CMT had a 1.8mm thick tip and the Jesada 1.4mm. The thicker the tip the more re-grinds a manufacturer will get and the more life can be expected. As a general guide, it is expected that up to 20 re-grinds should be available from a router bit. The depth of the carbide tip was measured from the cutting edge to the back, and the CMT came out the best with 5.0mm, followed by the Carb-i-tool at 4.3mm, the T-cut at 3.7mm and the Jesada at 3.3mm.

5.2.2 Cutting Test

A router bit used on a CNC machine must cut cleanly over many metres. Wood varies in density and structure within any species, so it was not considered a fair material for a cutting trial. Previous trials have taken place overseas using manufactured board that is of consistent quality. Board coated with a hard melamine surface will present a particularly grueling test for carbide tipped routing tools because the melamine will erode the tip quicker than the board itself. An American trial (Burkin 1999) ran a large number of bits through 82
It was appropriate to provide a similar test to Burkin as it would make the test results comparable to what has been done before. Research will often be based on a set of standards so it was decided to adopt the previous American trial as a starting point.

This trial used a CNC machining centre with an automatic tool change. Each bit was mounted in an industrial ISO-30 tool holder as it was the common tool holder of the time. Precise measurements were taken (Figure 29) to ensure the length of each tool was known. The machine would then be capable of plunging all tools to the same depth on both the MDF and particleboard sheets. A depth of 10mm and a feed speed of 6 metres per minute at 24,000 rpm was chosen for the trial. The settings were determined for optimal performance by technical data supplied by Leitz tooling. The CNC machine would provide a constant feed speed, depth and load, making for a very fair comparison of all four tools.

Medium density fiberboard (MDF) is a popular product in Australia, so it was decided to start with this and end the trial with chipboard. In all, each bit was run for 144 metres of MDF followed by 36 metres of chipboard, for a total of 180
metres or over 550 feet, double that of the American trial. The American trial had
bits breaking, and chips appearing after less than 10 metres so it was thought
that a similar result would be seen in this trial.

5.2.3 Results

Sheets 2.4 metres by 1.2 metres were used for the trial. Grooves were run along
the length of the sheet, one sheet per cutter as shown in Figure 30. The grooves
were spaced 6mm apart and this allowed three lots of 20 grooves to be run. The
machine was stopped after each 20 grooves (48 metres) to see the result. No
chips on any sheet at any part of the 144 metres of MDF were produced by any
of the four router bits. MDF is an excellent product and the melamine surface
adheres very well to the fine surface of the board. The author assumes that this
was the reason for the good results. The fact remains that the router bits were
cutting a highly abrasive melamine surface that should have produced some
wear on the bits. After a further 36 metres of cutting on the particle-board stock,
not one single chip was produced by any of the four tools. This is an amazing
result, particularly when it is considered that the T-cut bit cost $8-10, the Jesada
$31, the Carb-i-tool $31.90 and the CMT $35 (at the time of the trial).

Figure 30 (Running the tool tests)
A finger-nail test on the cutting edge of each bit provided an indication as to the wear factor of the tool. In addition, each tool was assessed by sight with a magnifying glass and measured with a Vernier caliper for any diameter change due to wear. The T-cut bit had a chip in the edge, but this was present when the test started. When the cutting tip of each tool was inspected after the initial 144 metres of MDF, the Jesada tool showed paint worn (green arrows) from the inside of one gullet and almost nothing from the other (See Figure 31). This indicated that the cutters were not even, and only one was doing the work. The other three bits had similar wear in both gullets. After the chipboard was run, the gullets were inspected again (red arrows) and all four bits showed more signs of wear on one gullet than the other. No change in the diameters of any tool was seen after measurement with a Vernier caliper.

Figure 31 Wear on only one flute confirms cutters running un-concentric
5.2.4 Conclusions

There is no doubt that all four cutting bits trialed were long lasting. The test was more rigorous than Burkin (1999). The surprising outcome was the performance of a tool costing $8 to $10 against the others at four times the price. It is highly likely that the quality of the Australian-made board used in the trials contributed to the low wear of the four tools. The interesting result from this trial is the amount of wear on one of the two cutting tips on all four cutters and this is a clear indication that the runout of tools held in a collet chuck is a factor in both quality and potential feed speed on the CNC machine. The runout evident on all four cutting tools is enough to justify the use of higher quality tools even for small batches.
5.3 Cutting with CNC (trial)

Generally speaking there is a tendency for CNC machine programmers to apply the tool feed in a clockwise direction around the work piece. A clockwise rotating tool will therefore be cutting with the tooth progression travelling the same direction as the work piece feed. This is referred to as mechanical feed, or down cutting. There is an expectation this type of tool application will improve the quality of the work piece surface. In previous controlled studies Ashley et al. (1998) Holmesglen Institute performed in conjunction with CSIRO Forest and Forest Products on thirteen species of juvenile and mature Australian hardwoods, this improvement was proved to be negligible.

As described in the previous chapter, there is also a tendency for manufacturers to use low-cost, small diameter tools when processing solid wood on CNC routing machines. This is in spite of technical information suggesting that this practice is inefficient. While a small diameter, low cost tool will cut wood and wood based products, they lack the peripheral speed of a larger bit and as a result, will not produce the same quality surface. This chapter describes a trial to see the difference between a small diameter tool and a large one. The cutting was performed with two tools of different diameters to provide an indication of the more appropriate cutting solution. The test was not performed using similar tools of different diameters, but using an “off the shelf” small, low-cost tool compared to a large diameter and more expensive “off the shelf” tool.

The purpose of this trial was to determine the optimum tool application for various diameter tools considering the tendency of the material to move on the vacuum holding devices under increased cutting forces, and to splinter at the beginning and end of the cut. A cross-grain test was considered to be the most demanding, and to offer the most useful results, so this is what was done.

5.3.1 Methodology

For each test a CNC machine was used to make a reference cut 50mm from either end of a 650mm X 150mm X 20 mm machined pine boards. The cut was
only 4mm deep and made at low speed to minimise material movement. The reference cut was made in every case with a large diameter tool. A parallel cut was then made with the test tool. A Vernier caliper was used to measure the result.

Three (3) standard tubeless cups were used to hold each piece. The vacuum cups were 135mm X 108mm X 3 cups = .043m² surface holding area at 6 bars. The pods were in used condition. Down cut machining (mechanical feed type) and up cut machining (hand feed type) were used. 20mm thickness Radiata Pine was used for all trials. The cut was across 140mm of material at various feed speeds using the two test tools. Five boards were used for each trial. Each board was cut from the same pack, allowed to condition for 4 weeks, then dressed all round a few minutes before the trial.

In the first test an 80mm diameter multi-blade hogging type tool in a HSK spindle was used as shown in Figure 33. The tool cost eight hundred dollars. The tool tip speed was 72 metres/sec at 18,000rpm. Eight, twelve, sixteen and twenty-four metres per minute tool feed speed were used to remove a 10mm depth of cut. The results were no material movement cutting in either direction (up-cut and down-cut) at any feed speed. In addition, there was minimal splintering of the wood at either end of the cut in either cutting direction, even at the highest feed speed of twenty-four metres a minute. The author defines “minimal splintering” as that being able to be sanded out.102

In the second test a 16mm diameter single cutting edge turnblade type tool in a HSK “Thermogrip” chuck was used as shown in Figure 32. The tool cost two hundred dollars. The tool tip speed was 10 metres/sec at 18,000rpm. Eight and twelve metres per minute tool feed speed were used to remove a 10mm depth of cut. The results were no material movement at 8m/min in either direction. At 12 m/min with an up-cut there was no movement but with a down-cut the material moved .4 to 1.2mm. Splintering of the wood occurred at all feed speeds, with a greater tendency at higher feed speeds (over 12m/min). Splintering was more evident at the end of the cut when an up-cut was used.
Figure 32 16mm Diameter Turnblade tool

Figure 33 80mm Diameter Hogging tool
5.3.2 Conclusions

Tools with high tool tip speeds (large diameter) were capable of heavy stock removal at high feed speeds in either cutting direction with no measurable movement of material due to cutting forces, and minimal splintering of the work piece. A down-cut reduced this splintering. Material movement was determined by measuring with a digital Vernier caliper, the distance to the end of the board at the start and end position (Figure 34). Given that the material is held only by vacuum pods and does not rest against a mechanical stop, if the material moves during the cut, these measurements will be different.

Tools with low tool tip speeds (small diameter) were not suitable for large removal of stock at feed speeds higher than 8m/min using a down-cut (mechanical feed) due to excessive material movement due to cutting forces. No measurable material movement was evident on large removal of stock using tools with low tool tip speeds (small diameter) at feed speeds higher than 8m/min utilising an up-cut (manual feed type). An up-cut produced break out at the end of the cut. This was reduced with the use of the larger diameter tool. A down-cut did not produce any significant break out at the beginning or end of the cut even at high feed speeds. An up-cut also produces longer tool life and requires lower power consumption (Leitz 2002). With an unfavorable fibre flow; the surface finish may not be as good as with a down-cut. Using an up-cut is contrary to machining processes generally used on CNC machinery in Australia. In the majority of cases a down-cut is used.
It is recommended to use an up-cut when roughing solid wood with small diameter tools. Roughing is defined as a pre-cut, leaving no more than 2mm for a finishing cut. Using an up-cut will allow the use of greater feed speeds without any material movement due to cutting forces, although some splintering may occur at the end of the cut. Use a down-cut when roughing solid wood using large diameter tools as this reduces the tendency for the wood to splinter at the beginning and end of the cut. A down-cut with large diameter tools has no measurable affect for the material to move due to cutting forces.

Figure 34 measuring the test pieces.
Figure 35 Common cutting directions for static and CNC machines
5.4 Improving Production Efficiency on CNC Equipment

Most furniture components processed on CNC machines are run singly. Susnjara (2002) states “Chair making on a CNC router does require a unique spoil-board with the part holding fixtures for each unique design.” They are placed either on a spoil-board or vacuum device against a pre-set stop. The stop is usually a retractable pin that is set by the machine maker at the factory and is set to the zero point of the X and Y machine axes. When the program is started, the stop device drops below the level of the workpiece and the cutting tool has free access to the top and four sides of the workpiece. The processing takes place at the right hand end of (most brands) the machine. Further processing can be done at the left hand end of the machine and the component can be positioned while the part at the right hand end is being processed. Thus, there is very little wait time between parts. The part machined on the left of the machine will be a mirror image of the part machined on the right. If a right hand chair leg were to be processed against the right hand stop, the part processed against the left hand stop would be the left chair leg and a pair would result. If the part were symmetrical, both left and right parts would be identical.

Many furniture components are delicate sections and the more common of these are found in chair making. Most pieces are between 50mm and 70mm in width. These present a problem for CNC machines as the components are difficult to hold with vacuum. The most efficient method of holding these small parts are with a mechanical clamp but this means that the clamp usually needs to be moved to complete the profiling. Holding a single piece on a vacuum pod may result in the part moving during profiling, especially with a heavy cut. The depth of cut could be processed in two separate cuts but this doubles the cutting time of the part.

Batch sizes can be improved by combining two or more parts required for the same job. To explore this, a common dining chair leg was processed. The chair is upholstered, and some parts of the chair are best made on static machines. CNC machines are entirely unsuitable for planing timber in square dressed
sections. With this particular product, the front legs and rails are processed normally; that is to say, using basic static machines. Mortices and Tenon’s can be cut on the CNC or with static joining machines. The rear legs lend themselves to cutting on the CNC machine. The chair is shown in Figure 36.

Figure 36 Chair legs made on CNC machine in small batches
The rear legs are of the same profile but with mortices on the inside of each one. Profiles can also be run at the front or rear stops of some machines, and in larger versions, against (material) stops in the centre of the CNC machine table. In this scenario, up to eight (8) parts can be run in four (left and right) sets. With this product it will therefore be possible to program only one leg (left or right) and when it is run on the opposite end of the machine, a mirror copy will be produced. As single chairs are very rarely sold, manufacturing in pairs is a sound decision. In this way, two, four, six or eight chairs can easily be manufactured.

A CAD drawing was made of the intended chair leg and this was saved as a DXF format file. The file is converted to machine code by the post processor on the (CNC machine) graphic interface. The method varies from machine to machine but in the case of the Weeke machine (at the time of this work), the process is to draw the component on various layers in order that the machine software is able to identify the separate processes. The layer contents are shown in the following list:

- **Layer 0**: Panel layer, draw panel (will be thickness from the part drawing)
- **Layer 1**: Routing layer, no tool data is transferred; enter on machine from selection of available tools.
- **Layer 2**: Vertical drilling; draw circles in CAD, transfers 12mm drill depth, can be altered on machine.
- **Layer 3**: Horizontal drilling, draw boxes in CAD, the size of the hole. Will include “c” (4th) axis but may need to delete unwanted entries as machine interface may not be able to identify the correct angle and may enter more than the one hole.
- **Layer 4**: Sawing at 90 degrees with saw in X or Y axis. No depth entered, alter on machine.
- **Layer 5**: Sawing at angle, uses 4th axis device (if fitted). No depth entered, enter on machine.
In the case of the chair, all profiles were generated on the routing layer and the mortice depths adjusted on the machine. The resulting (partial) screen display for the transferred CAD image is shown in Figure 37. Two legs can be seen on a wide board. A gap is required to allow the cutter to pass between the two pieces. Cutting two legs from the same board allows the use of wider material and improved hold-down strength. The holding device is a rectangular pod that raises the board 100mm above the table. The pod can be seen as a yellow rectangle in the figure.

![Figure 37 CAM screen display for chair legs in batches](image)

Also in the figure, the cutting tool can be seen at the start locations of both pieces. The direction of rotation can be seen, as is the tool cutting direction.
(path). In the information box at the lower of the picture can be seen the panel width of 230mm, the length of 932mm and the thickness of 34mm. On the bottom right of picture can be seen the final depth of 31mm (expressed as $Z$-), the feed speed of 5 metres per minute and the tool number. The tool in this case will be a spiral serrated bit of 20mm diameter numbered 138 and is taken from the on-board tool change. The data relating to the tool length, radius, maximum cutting length and permissible feed speed is stored in the computer. A 20mm diameter cutter can make one cut to 31mm deep but a smaller diameter cutter may need two passes at 16mm each.

![Figure 38 Vacuum pods used to hold the part](image)

To hold the 230mm wide board onto the machine table four vacuum pods were used (Figure 38). The vacuum pods have a rubber seal and these are about $100 each. In order that the legs remain part of the board and the cutter not cut through to the expensive rubber seal, the depth of cut was stopped as previously
mentioned at 31mm. This leaves 3mm on the board to hold the legs and waste together. The rationale behind this is that it eliminates expensive jigs; simplifies material handling; keeps the legs in pairs until a further process and increases production time on the machine. In the case of a mass production job, the pieces would stack easily on a pallet or trolley and would not be in danger of collapsing due to uneven floors. Damage to the parts would be eliminated because the pieces are held in the board until almost ready for assembly. Materials handling time is greatly reduced as the operator is handling one piece of timber, not two. Keeping the machine running longer is important as the longer a machine runs, the more economical it is. The machine has to start up and position the cutting head at the start point of the program irrespective of whether there is one part or two in the cycle. It is evident that the more parts in the cycle, the more economical it is.

Figure 39 Processing detail.
This exercise could have been done with four or six legs in the program; however that would require gluing of more boards to achieve a wider piece and this presents program design issues, especially for a load bearing furniture member such as a chair leg. Additionally, the two legs can be machined from a commercially available timber section of 250mm X 38mm.

As the legs must be sanded prior to finishing, the whole wooden piece (legs and off-cuts) can be fed through a wide belt sanding machine (Figure 40). This machine would sand the two parts on the upper surface, then turned over to sand the under surface and to separate the parts. The off-cuts will fall into a waste or recycling bin at the rear of the sanding machine. This method ensures that the parts are not separated until they are completely finished and ready for assembly. If a sander is not available, a thicknessing machine can be used.

Cutting the chair legs on a CNC machine takes less than five minutes a set. This means twelve chairs can be manufactured every hour. To do the same work on conventional equipment a skilled machinist needs to mark the outline of the two legs; cut both legs on a band-saw; shape the legs on a spindle moulder using two jigs and then bore out the slots on either a slot-mortising machine or combination machine attachment. Even with a well-drilled work sequence, it is not expected that more than four sets of legs can be made in an hour. There is no guarantee that all the legs will be exactly the same. With a CNC machine the piece is not removed from the machine until all of the work is done so nothing moves and it's all held firmly in place until it's finished.

The serrated cutter is used because the chair is upholstered from the seat to the top of the back. A serrated cutter removes wood more efficiently and will cut faster. It is necessary to just lightly sand the legs from the seat down. If the chair is all polished, a straight cutter would be used. The cutter itself is held in a chuck that does not have a collet and nut. The "Thermogrip" chuck is described in the chapter on CNC tooling.

A time-consuming, possibly dangerous and difficult job is made easy using this method of manufacture. The components that are required to be run on a CNC
machine are run in batches of two and the pairs are made by running one set on the right and one set on the left of the machine. The set up time in the case of this product was less than five minutes and required the pods and table rail to be positioned and the program called up and assigned to the two ends of the table. The cutter is a standard tool but if this required inserting into the tool magazine, only another few minutes would be needed. The cutting time of each leg produced cannot be altered but the machine wait time; movement time; setup time and material handling times are all reduced with this method of manufacture.

Figure 40 Sanding (or planing) separates the parts.
5.5 Batch Size One in Sheet Materials

Holding small wood furniture parts onto the CNC machine table presents problems when increasing the number of parts in the one machining cycle. This problem is not a concern when using sheet materials due to the large surface area of the sheets that can easily be held in place by vacuum. The machining of free-standing furniture in solid wood is not common but can be demonstrated using manufactured board or solid wood where the parts are of sufficient dimension that adequate hold-down can be guaranteed.

5.5.1 Stool

With the assistance of a CNC machinery manufacturer; a small piece of furniture was produced (Figure 41). The piece was a small stool in three parts; a back, seat and brace. The product was cut from plywood. A complex jig was required to hold the part and this took eight hours to make. The jig consisted of a board for the base and three raised sections; one for each part of the stool. The raised sections are necessary to allow the use of cutting tools where the length of the tool would cut into the base board of the jig.

Figure 41 Batch size one processing.
A detail of the jig is shown in Figure 42. The three sections that raise the furniture part are glued to the base section to eliminate leaking of air that would result in a loss of vacuum. Round (6mm) rubber was used to create the vacuum and this was achieved by using a negative tool offset in the program to force the cutter to machine a groove inside the extremities of the parts. The rubber can be adhered into place. Holes were then drilled through the part and these holes line up with the vacuum pods under the jig. An alternate method would be to hold the base of the jig down onto the top of the vacuum pods and then to supply a secondary vacuum to create the hold down on the three raised sections of the jig. This would have added a further three hours to the construction time of the jig.

Figure 42 Detail of stool jig
The demonstration took place at the machine manufacturers training centre in Gutersloh (Germany). The machine used was a four axis CNC processing centre with an aggregate (providing an additional half axis) to cut the required angles for the angled rear of the stool. The aggregate allows the setting of a cutter at a predetermined angle and this can then be applied to the fourth axis of the CNC machine. This is referred to as “four and a half axes” but five axes machines are now available at a competitive price point that will enable this work to be done. Advice from the CNC machine manufacturer was that small, multiple parts would be very difficult to nest on one jig for batch size of one. The use of a four-axis machine puts this type of job outside the framework of this work. The completed stool is shown in Figure 43

Figure 43 Childs stool in plywood.
5.5.2 Wine Table

A piece of furniture was produced as a batch size of one as shown in Figure 44. A small wine table was designed on a CAD program. Two connecting legs and the table top were arranged so the top was in the centre of the machine table and the legs either side of the top. One piece of plywood or other manufactured board was placed on the table and the entire table was cut as a batch of one. Two cutters were required, the first straight tool to cut the external shape of the top slightly oversize, then to profile the legs to finished size. The second tool was a shaping cutter and this could be changed to provide different edge treatments to the top. The program was run on a CNC router. The top was run inverted in order that grooves could be inserted into the underside to accept the crossed table legs. The table could be sold as a flat-pack product.

Figure 44 Table from one piece of material.
5.5.3 Chairs

During a visit to Purdue University in 2011 batch size one was discussed with Professor Rado Gazo. Prof. Gazo was currently working on batch size one and had produced a chair to demonstrate the potential. Again, flat panel products were used to ensure good adhesion to the table. The chair was cut on a flat table machine in a nested program. Similar to most nesting cycles; the first depth of cut was made with a cutter offset away from the job by 0.2mm and to within 1mm of the table. The second cut was made to the finished dimension and through the job to finish and separate the parts. This type of manufacture is not possible with individual solid timber pieces. The design of the chair is limited to the capabilities of the machine in a two-dimensional plane. The chair is shown in Figure 45.

![Figure 45 Batch size one by Prof. Gazo (Purdue University)](image-url)
5.5.5 Further Examples

Further examples of batch size one was available from other major machinery suppliers. Chair parts can be seen in Figure 46. In this example a flat table machine was used to hold the jig. The time to construct the jig is dependent on the number of parts and complexity of the CNC machine program. In this case it must also be noted that the jig is attached to the machine table with Allen screws that take ten minutes to fit. This is consistent with Mo et al. (2001) when it is noted that “the average set up time for a CNC machine is 9.0 minutes.”

Figure 46 Batch size one chair parts courtesy Homag machinery
6. Discussion

This section contains the Author’s discussion leading to the research results and is based on the literature review; investigation; extensive industry visits, consultations and interviews, and work performed during the study.

6.1 Batch Sizes

Mo et al. (2001) states “In an ideal situation, the goal for CNC technology is to make one complete set of furniture components ready to assemble. Is it possible to manufacture one coffee table or one dining setting economically? Whether the parts needed to produce these products are machined singly or as a complete set at the one time, the aim is for efficiency of production for a cost-effective production outcome. Reduced stock inventory is the result of producing in small batches and eliminates the need for extensive storage. It delivers flexibility in manufacturing and improved staff morale due to more interesting work.

Mo (2001) states that; “There is no obvious difference between manufacturing using a CNC machine and that using traditional wood machining technology”. In principle this is correct but in reality there are significant differences. Firstly, the manufacture using CNC machinery is quick to set up; does not require complex jigs; does not require skilled workers; is quicker to run; predictable in quality and production time. Single part manufacture on a CNC machine is accomplished by the calling up of the part-specific program from a library; ensuring the correct tools are present in the tool magazine and placing the part against a stop on the machine table. The parts are then manufactured in sequence using (up to) eight loading points on the machine so production is continuous. One part can be produced economically. Where there is no obvious difference is where the enterprise use the CNC machine the same way they use static machinery; where they do not take advantage of the increased outputs of the CNC machine.
6.2 Inventory and batch size

Inventories are materials that an enterprise carries to provide inputs to the production process. They consist of raw materials, work in progress (WIP) and finished goods. They can represent a significant proportion of the total assets of a company. The lower the inventory value the lower the manufacturing costs will be. However in the Australian context an inventory close to zero may not be possible. Most furniture manufacturers need to respond quickly to customer orders and cannot afford to wait for materials to be delivered. Unlike Carl Hansen, materials will not be delivered daily and may take at least a week after the order is placed. Most companies are content to hold an amount of inventory they feel comfortable with. As wood is usually sold in packs, several packs of various dimensions will be available for manufacture. For the purpose of this discussion it is assumed that the inventory is of furniture grade wood.

If demand (orders) can be forecast and constant over a long period of time, the furniture could be produced to meet the predicted demand. However this is rarely possible in the Australian context. Mo (2001) states “One major concern was the small customer orders in the Australian market”. Because of this, orders must be filled as quickly and as efficiently as possible. If the order cannot be filled within the time frame demanded by the retailer, the order and future business could be lost to another company (competitor). As orders are unpredictable and small, reduction in lot sizes to match the actual order quantity are required. Economic Lot Size (ELS) was developed in 1913 (Quarterman 2015). The principle was to weigh inventory costs against setup costs over a range of batch sizes (Milgrom 1990). In this model, the Economic Lot Size (ELS) is where Total Cost is the minimum possible. However, with unpredictable orders in terms of time and quantity; every operation should manufacture what the customer needs immediately in "batches" of one unit. If a batch is one complete set of furniture components and the order is ten; then the ELS will be ten.

Reinertsen (2009), a thought-leader in modern manufacturing along other luminaries such as Goldratt and Deming; makes the argument that “Small batch
sizes and low variability are not universally desirable. Rather, there are economic payoff functions for each and cases where reducing batch size or variability can actually be the wrong economic decision. One should consider the total cost, as opposed to blindly believing that small batches are always better or striving for one piece flow." It may be desirable for a furniture factory to hold some stock of common parts and these could be manufactured in reasonable quantities when there are few orders in the system. Apart from a limited amount of stock items, a manufacturer should look to a batch size that matches the order quantity. The issue really is of cycle time. Is the cycle time of single component manufacture better or worse than manufacturing parts in a group considering the setup and running times of each?

6.3 Cycle Times

Kilpatrick (2003) comments that one barrier to successful implementation of lean principles is that “The company implements the building blocks in the wrong sequence. For example, if batch sizes are reduced prior to reducing changeover time, and changeover times are lengthy, equipment utilization will drop, and the ability to serve customers will be reduced”. With CNC machines the changeover time is the time it takes to:

1. Load the program
2. Load the cutting tools into the tool magazine
3. Set the jigs to hold the part(s)

Loading the program into the machine takes 20 seconds and it is likely that the program can be accessed via LAN or that the program is present in memory. Setting the cutting tools could take up to five minutes for each tool but it is likely that the basic tools will be present in the magazine resulting is a tool change time of zero. Shaping tools will possibly need to be changed but if an efficient quick-change tooling system depicted in Figure 13 is used, the changeover time for shaping tools will be a few minutes depending on access to the cutting tips.
Single Minute Exchange of Die (SMED) is a well-known principle in lean manufacturing developed by Shingo in 1985 (Shinguru Dandori 1983). It claims that by reducing setup times to less than 10 minutes, there is no need for specifying batch sizes and quantities equal to customer demand can be produced. It is apparent that the setup time excluding the setting of the jigs is less than ten minutes and in the majority of cases; excluding special jobs to customer order, the time is closer to five minutes. Setting the jigs to hold the parts therefore becomes the deciding factor when it comes to the question of running single parts or a group of parts machined together.

6.4 Batch Size One

Batch size one is possible on CNC machinery provided complex jigs are constructed and there is adequate vacuum to hold the pieces onto the machine table. This has been proved at the Bern Institute of Applied Sciences through personal observation (Figure 47), but is not widely used due to the high volumes of orders available to European Countries, for example where there is a large population resulting in large furniture consumption located within a relatively small area. European transport links are excellent and goods can be shipped to half a dozen Countries within a very short period of time. In Australia the distances are vast compared to Europe, and the orders much smaller. It is estimated that as much as 90% of furniture sold in Australia is imported and this figure is not expected to improve.
A major concern for manufacturers is imported product and this is produced at the lowest possible cost at high volumes. Imported product is in most cases sold on price and domestically produced Australian furniture takes up the higher quality element of furniture sold in this Country. Furniture produced in Australia on a CNC machine needs to be of the lowest possible cost and outlay; the highest quality and with zero defects or re-work.

The processing time of a furniture component can be altered by using alternate, higher-production cutting tools or by sacrificing quality for time. The reality is that if all the production variables are common; the actual machining time of a product (the number of seconds that the cutter is cutting the wood) will be the same whether it is produced singly, in a small batch, or a large batch. The production variable that potentially can be altered in favor of more cost-effective production is the non-value-added component of the CNC process. This includes waiting
time inclusive of the non-cutting movement of the tool; tool change time, and set-up (change-over) time.

Batch size one could mean processing every part of the piece of furniture one at a time or it could mean processing all of the parts together in the one machining cycle. Both are feasible manufacturing options. The difference between the two types of manufacture is that one requires no jigs and the other requires a jig to hold all the parts. It has been shown that a jig to produce a simple stool takes at least 8 hours to make and test. A manufacturer would need to consider future use (sales); storage and deterioration of the jig; cost to make the jig and the possibility of variations to the product before committing to an expensive jig-making exercise.

David Beaumann of Davis Furniture (Victoria) comments that "We make single job lots now and we make them to order, no two tables are the same." While David was generalizing, it does cause some concern as to whether or not a manufacturer is able to commit labour, materials and machine down-time to affect the manufacture of complex jigs that are unable to be easily modified for customer demand. Mitchell et al. (undated) comments "Small batch sizes are possible only when (furniture) set-up times are eliminated or significantly reduced."

6.5 Multiple-Part Processing in Small Batch Sizes

The requirements for multiple parts processing using a single jig are that the CNC machine be given enough space to move materials into and out of the machining area. Space is also required for jigs if required and the more complex the machining cycle, the more complex the jigs will be. The jigs will need an extensive area in which to store them. Any raw material used for the parts will also need to be pre-machined more precisely to avoid cutting tools of various diameters crashing into components held on the jig. A jig to profile doors and drawers on a CNC machine is shown in Figure 48. If any of the profiles in this job require edge treatments such as dowels or Mortices, an aggregate must be used
and the parts spaced far enough apart to allow the aggregate access to the edge. In this scenario, fewer parts could be machined and two jigs may be required.

Another issue that will be a problem is that if a Company embarks on single batch sizes using a jig to hold multiple components, the technology to achieve this outcome must work flawlessly every time. If any piece in the layout were to move, or the machining be of poor quality, or the wood itself show signs of deterioration due to chipping, splitting, or other unseen defects, then the whole process will need to be repeated as the manufacturer would not be able to replace one piece of the set. The CNC machine would be held up for an extended time while a new set of parts were pre-machined. The resulting unused parts from one of the two sets made would be a waste factor the Company would need to bear. Further to this, if a part were to be damaged during a subsequent (assembly) process, it could not easily be replaced. In addition, the costs associated with setting up a complex jig cannot be recouped with just one order. It is unlikely that Australian Furniture manufacturers would commit resources to a technology that could not repay itself in the short term.
There are issues surrounding furniture machined in the one cycle on a single jig that need to be addressed before proceeding with this technology. These issues are as follows:

1. Equipment with strong vacuum pumps needs to be in place.
2. Complex jigs need to be constructed in order to firmly support the various work-pieces.
3. Highly skilled operators need to be involved to properly program the machine, allowing for tooling and wood properties.
4. A four axis machine is highly likely to be required to complete all the cutting necessary, especially if any curved or angled sections are to be manufactured.
5. Not all furniture lends itself to manufacture as a batch size of one and appropriate furniture needs to be identified.
6. The time to prepare the machine for the initial run, taking into account the high cost of the complex jig and the machine down-time, needs to be assessed to ensure a saving can actually be made over the life of the furniture item (projected units of sales).

7. Other methods of effectively machining multiple parts without the use of expensive equipment, jigs and tools are available and should be assessed for suitability before a complete set of parts is considered. (See chapter on improving production efficiency on CNC Equipment).

6.6 Single Part Processing in Small Batch Sizes

There are advantages in machining single parts on a CNC machine. Single parts are not held in a jig but placed against a zero stop. The two surfaces need the same pre-machining as those held in a jig but the machining of the four sides is less important than the sides on a piece used on a jig. This is because in a single piece there is no jig on which any offcuts might fall and catch on the rotating cutter. As a single part, all the offcuts fall into the well of the machine.

It has been shown that loading a single part onto a CNC machine takes 12 seconds. Fitting a complex jig to the machine takes a minimum of five minutes and this was timed using the wine table jig. Ten minutes is required to fit the jig shown in Figure 46. Fitting a heavy jig may also require two operators. Comparing a small batch size of five coffee tables with nine components in each, we see a total of 45 parts. Whether or not the parts are machined individually or on a jig as a set, the parts have to be positioned by hand. Loading the parts individually against a machine shop requires only that the operator places the part against a stop. Loading the parts onto a jig requires the operator to carefully position the parts on rubber seals because a stop will not be available (Figure 49). It is evident that the loading of parts onto a complex jig will take longer than for individual parts run separately.
If parts are manufactured separately, additional parts can be made during the production run for stock or re-work as required. This is not possible when all of the parts are machined in the one production cycle on a jig. If a change in the design of the product were to occur, production of single parts would require only a change to the CNC program. Parts made in multiple on a jig may require a new jig to be made. All the parts need to be held firmly onto the jig prior to starting the machining cycle. The operator may use a rubber hammer or may place a plastic sheet over the jig until the vacuum has taken hold. This adds time to the process.

Stacked tools are used extensively for joinery and window manufacture and can also be used to manufacture furniture. Stacked tools are shown in Figure 50 and incorporate two or more cutting profiles into the one tool. Stacked tools increase
the capacity of the tool change magazine and reduce the tool change-over time if the tools are grouped together for efficient production. For instance; the profile to shape the edge of a chair leg could be grouped with the profile to cut the Tenon on the end of the leg.

Stacked tools cannot be used in a multiple-part machining strategy due to the depth the tool needs to travel to use the top profile. Only one-part processing can take advantage of this tooling advantage.

The lowest batch size is not the best batch size for solid wood furniture and all other issues need to be considered. Perhaps the real question is not whether a batch size of one is possible, but whether or not it is feasible to increase the complexity of the process and whether this actually reduces manufacturing costs. A rail for a coffee table takes the same amount of time to process as a single
component as it does in a nested batch. The tool travels around the part at the same speed; it's the machine movement time that improves. As an example, a coffee table with a top, four legs and four rails (two long and two short) may be a candidate for Batch size one in a multiple-part machining cycle (Figure 51). The legs, if square will need pre-planing to finished size and only the mortices (or dowel holes) and a taper could be done with the CNC machine. The rails would need pre-planing in thickness only but one edge would need to be planed to sit against the stop. The widthing any edge shaping and morticing (or dowelling) could be done on the CNC machine. The table top would need pre-planing in the thickness but the edges; any moulding and any locating machining (dowel holes) for the attaching of the legs and rails could be done on the CNC machine.

Figure 51 Batch size one layout for a coffee table

In this scenario, due to the requirement to produce Mortices and Tenon’s (or dowel holes, or mechanical fitting holes) on the CNC machine with aggregates, a large jig would need to be made that would allow space for the aggregates to work in. The jig would need inserted rubber to create a vacuum and stop blocks to accurately position the parts (shown in brown) to speed up the loading of
parts. This large jig would need to be mounted onto the machine table, fitted with supplementary vacuum hoses and then stored when not in use. These actions need to be taken into account when making a decision to attempt a small batch size machining multiple parts in the one cycle.

We can now look at the machining to the suggested layout in Figure 51 and apply some time to the process. In a multiple-part process there will only be three tool changes; one to insert the straight cutter, a second to change to a shaping cutter for the rails and a third to change to a different shaping cutter for the table top. Once changed, the tool would machine all of the parts at the one time before the next tool was required. At a minimum of seven seconds per change we find a total tool change time of 21 seconds. This assumes the cutting tool is located next to the cutter-head and not on a tool-change located at the rear of the machine in which case the time will be more, but relative to both situations.

In the case of single-part processing, the times are as follows:

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Tool Changes</th>
<th>Seconds to Change</th>
<th>Number of Parts</th>
<th>Total Change Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>2</td>
<td>7</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>Rail</td>
<td>2</td>
<td>7</td>
<td>4</td>
<td>56</td>
</tr>
<tr>
<td>Leg</td>
<td>1</td>
<td>7</td>
<td>4</td>
<td>28</td>
</tr>
<tr>
<td>Total tool change time (in seconds)</td>
<td>98</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Given that the actual machining time for the combined lengths of all of the parts will be the same whether or not the table is machined in a multiple-part process or a single-part process; this time will be ignored. The difference in processing time comes down to the remaining factors. Factor one is the tool change time and in the case of multiple-part processing we find the rails require a straight and a shaping tool. The legs require a straight tool. The top requires a straight tool and a different shaping tool to the rails. In the case of multiple part processing
the tool change time will be only 21 seconds and in the case of the single-part processing we find the total tool change time is 98 seconds; a difference of 77 seconds.

Earlier we assumed five tables would be the batch size so the 21 seconds will be multiplied by 5 to arrive at a total tool change time of 105 seconds. The tool change time to run individual components will not change because all of the rails will be run together; the same for the tops and the legs. We see from this simple calculation that the tool change time to run multiple parts on the one jig is longer than for single parts (98 seconds). The second factor that needs to be taken into account is the long movements of the work-head over the large jig compared to the short movements that are needed when individual parts are placed at the zero stop. It can be seen from this simple exercise that there is no processing time advantage when all of the parts are combined into the one machining cycle.

The time lost (debatable) by running all the parts in a single machining cycle is saved by not finding, positioning and attaching a supplementary vacuum to a complex jig, then putting it all away again when the job is complete. The use of a secondary jig is problematical as it is another layer in the hold down sequence on the CNC machine. A single part held by the machine vacuum pods is the best hold that can be achieved. Only two seals are required; that of the pod to the machine table and that of the component to the top of the pod. In the case of a supplementary jig there are three seals that need to be made. These are the seal of the pod to the table; the jig to the pod and the component to the jig. The issue of multiple parts being held at the same time further increases the chance of a leak in vacuum, adding to the potential problems.

6.7 Author’s Recommendations for CNC Manufacture

- Machines and software should be purchased for a recognized manufacturing need. Seek advice or use an independent consultant to advise on appropriate requirements. Despite the best intentions of the seller, machinery and software may not always do what the seller said it would. A mistake at this stage will cost the company for years to come.
For instance, it makes no sense to purchase a machine with inferior SK (ISO30) tool holders. The costs are the same as HSK that are (arguably) twice as good at reducing tool run-out.

- Standardize components where possible. Many companies should be able to look for components that are similar, and re-design some pieces to create same-size components over several product ranges. Start with shelves and drawer sizes and then move on to other components.

- Keep all profiles less than 20mm deep. This will allow the use of “system” tooling with constant diameters that simplify tool data entry. System tool bodies can be used to quickly mount different profiles and reduce tool change over time to less than thirty seconds. In addition, cutter heads mounted on an arbor will eliminate the collet that is the weak link in a collet chuck.

- Mounting frequently-used tools in new-generation “Tribos®” or “Thermogrip®” chucks will improve chip removal and extend the cutting life of the tool. Some CNC processing machines are capable of 24,000rpm and both collet chucks and hydro chucks tend to “open up” at this speed and increase run-out factors. The Tribos and Thermogrip chucks remain rigid to 40,000rpm.

- Purchase tooling as an investment, not an expense. Low cost tools usually serve a single purpose, are difficult and time consuming to manage with CNC, do not always offer a quality finish and can be inflexible, costing machine down-time and productivity. Investigate micro grain carbide that lasts longer, with the same quality finish.

- Most CNC machinery is under-utilized. Many are programmed to perform far below their capabilities (feed speed and cutting depth). Training should not just be about setting up the machine but include the application of the cutting tool to the work piece. The capabilities of existing tooling may be much greater than thought and the application of “advanced” tools could in
many cases double the production speed and material output of the machine.

- Quality should not be confined to the output of the CNC machine. Quality principles should also be applied to maintenance, cleanliness, tool holders and cutting tools. A CNC quality system will set a standard and the finished product will benefit.

- Get the right people. The right people are those who are able to add best practice and adapt to new furniture designs for CNC production. The operators can double (or halve) the production output of any CNC machine. Appropriate training, remuneration and a career path will ensure the loyalty of key employees and ensure high outputs.

- Employers must become partners with training institutes. Industry should actively seek the latest equipment and software for training, and support the training providers when applying for it. Employers must provide more practical training on in-house processes and allow the institutes to explore the “why” rather than the “how-to”. Australia is in danger of producing “operators” when we need “technicians”. We need thinkers as well as doers.

- High technology is suited to high-value manufacturing. Using CNC machinery to combat low-cost imported goods is futile. Manufacture quality goods with a focus on good design. Switch production if necessary. Educate the public about “Australian-made” and good quality.

- Investigate what components should be made on CNC machines and what is best done on standard machinery. Learn what the CNC machine can and cannot do. Don’t just run jobs; integrate the machine into the production line. The CNC processing centre can become a bottleneck in the production line. Know the set-up and production times and plan work sequencing accordingly.
• Increase the use of veneer board and manufactured panels, and reduce the solid wood component of furniture production. Environmental issues will gradually change the public’s acceptance of solid wood furniture. Design often follows European trends, and the trends there appear to be modern looks and functional design using alternative materials.

• Learn to use the expertise of other companies. It may be possible to include some other materials such as steel, glass or plastics into the product range. Designs could be seen as more “modern” and appeal to a wider consumer base.

• Software is a powerful tool. Use it as much as possible from design through manufacturing to assembly. If the software does not “talk to all other programs and all machinery” then it’s costing money. CNC machine software is not real CAD; it is workshop-oriented and limited in design capability. Consider the purchase of a proper CAD system to design a product, then post-process this design directly to the machine. This eliminates much of the set up time (reported to be an average of nine minutes in Australia). The right machines and software can build a manufacturing “system”, where many companies just have “machines”.

• Be creative. There are other ways to make furniture and it may not always be like “Dad” made it, or the way trades persons were taught in trade school. Look for a cost effective way rather than a “trade” way.

6.8 Training Recommendations for Small Batch CNC Processing

• It is highly recommended that furniture manufacturers provide employees with a basic CNC machining course prior to the delivery of their new machine. This initiative will save many hours acquiring basic knowledge and allow the trainees to focus the limited training time provided by the supplier on issues relating to the production capacity of the machine and not just "how it works." Following up initial supplier training with advanced
CNC training using machine software and CAD is a secondary measure to fully take advantage of the employees training mind-set.

- When the first CNC machine is introduced into a company, manufacturers may find they can now do things differently. Some effort needs to be given to providing some time and training so employees can come to terms with these changes in an ordered manner, and not stumble across them in the course of the day. Manufacturers need to consider advanced CNC manufacturing. Employees and managers will require new skills in modern production techniques, equipment and product design. Partnerships between training organizations and industry facilitate successful manufacturing processes and allows for the sharing of skills and experience. The craft-based training culture existing in TAFE Institutes and industry needs to be supplemented by a (CNC) production based training culture. As of the publication of this document, the training culture in Australian vocational education for the furniture industries remains one of craft.

- CNC manufacturing poses interesting possibilities for designers of furniture. Coupled with modern assembly methods, the production of furniture using CNC technologies, software and modern hardware needs to be investigated by every enterprise in order to optimize their CNC production. It may be possible to re-design furniture so that the CNC machine can produce a larger share of the processing required for each component. Ideally, the CNC machine should produce ALL of the processing (towards a batch size of one), but this may not be cost effective in some cases. Professor Rado Gazo at Purdue University (West Lafayette) Indiana was consulted and it is noted he is currently researching the items that best suit CNC manufacturing.

- There is limited design and manufacturing skills on CNC machining of furniture. European manufacturers have taken leading furniture design and manufacture the components with CNC machinery. Factories are
automated to deliver cost-effective parts for furniture designed before the advent of CNC machines. (see chapter on Carl Hansen and Son). Industry should study the manufacturing and design requirements to deliver innovative new designs quickly to the market place. Industry must learn how a large range and number of furniture designs could be manufactured whilst still allowing for relatively small orders.

• Quality control and flexibility are the prime consideration for most manufacturers using CNC equipment. Industry should learn how quality systems are implemented into the CNC manufacturing environment. Dwindling timber resources produce a need for better skills in the recovery and reuse of as much “waste” material as possible. The question should be asked “how many manufacturers use even a basic materials optimizer in their CNC manufacturing?” Manufacturers should learn how waste management systems are used in a CNC manufacturing environment and how innovative CNC production methods can improve product recovery, minimize production time and reduce materials waste, especially resource-based.

• Part fixturing (jigs and holding devices) are often based on traditional methods and may be unsuited to CNC manufacturing. Manufacturers should learn advanced and innovative methods of holding multiple parts in a single processing cycle. In order to achieve smaller batch sizes, operatives will need advanced skills in software, machine knowledge and jig design. In addition, manufacturers should learn how cutting forces affect job fixturing on CNC machinery. Manufacturers must learn the principles of small batch production and look at ways these can be implemented in the Australian context.

• Tools (cutters) used on CNC machinery are generally basic in design. The furniture industry often does not understand the cost benefits of appropriate tooling solutions. Manufacturers should learn how to apply specialized CNC tooling on CNC machines. It would be beneficial to learn
how to design optimum tooling (tooling magazine) configurations and how to optimize the delivery of the tool to the work piece. Manufacturers should learn how tooling can be used to effect furniture design and study tool feed speeds to optimize the productivity of each CNC process. There is extremely limited knowledge of emerging CNC technology available through literature and knowledge is usually passed on by the tooling suppliers. Manufacturers should be aware of the latest trends in high-speed cutting (HSC) technologies. Manufacturers should learn about chip removal from the CNC cutting area to improve surface quality, dust extraction and tool feed speeds.

- There are limited skills in the design of the CNC manufacturing installation. Machinery and software is often purchased and installed in a haphazard manner resulting in poor production flow and efficiencies. Price is often the main factor considered in a CNC purchase, ignoring the future costs when the equipment is unable to deliver on expected outcomes. Manufacturers should study the principles of efficient plant layout and software integration. Manufacturers should learn how bottlenecks caused by CNC machinery could be avoided.
7. Research results

This section contains the research results based on the literature review; investigation; interviews, extensive industry visits and consultation, and work performed during the study. The aim of this dissertation was to investigate the innovative use of CNC wood processing machinery for the flexible manufacture of furniture towards a batch size of one. Particular emphasis was placed on addressing a number of issues raised by Mo et al. (2001). The particular issues were:

- Unsatisfactory use of computer systems and equipment
- Poor materials handling and layout
- Trade practices instead of production flow systems
- Piecemeal use of technology
- Training and education

A comment was made that “In an ideal situation, the goal for CNC technology is to make one complete set of furniture components ready to assemble and eliminate batches of components on the shop floor.” The suggestion was made that several components could be combined into the one CNC program but only one manufacturer had considered this.

During this study many interested parties were visited and consulted. These parties included:

- Principal CNC machinery manufacturers located mainly in Germany and Italy and CNC machinery distributors located in Australia.
- Furniture manufacturers located in Australia, Denmark, Germany, Italy, Switzerland and Austria.
- Technical training centres and relevant higher education centres located in Australia, Germany, USA, Denmark, Spain, Canada and Switzerland; and
training professionals in Australia and overseas as listed in the acknowledgements.

- Tooling manufacturers located in Germany and distributors in Australia.

Information, observation and advice from the extensive number of visits and contacts are used widely in this work. The initial focus of the work was to investigate the combining of all of the parts of a piece of furniture into one CNC program as this was considered a true “batch size of one.” Further work was done to address the identified issues arising from the 2001 “Analysis of Current production Practices.”

7.1 Small batch sizes and batch size one

While the majority of those consulted on the issue of combining multiple parts into one program and processing them at the same time thought it was an interesting concept; most volunteered that it had been done before but was not universally accepted as a viable industry practice. No evidence was seen of this method throughout the industry in any of the countries and the only evidence of work done as experimentation was seen in several schools and Universities. The author has 25 years’ experience using and teaching CNC technologies and is likewise not in favor of combining multiple parts into one machining cycle.

It was clear that for the processing of kitchen cabinets; a nested manufacturing solution delivered the most benefits to the manufacturer. The benefits included reduced manufacturing time; reduced skill levels for machine operators and reduced equipment costs. Small batches could be produced economically. For a manufacturer producing furniture in either solid wood or a mixture of veneered boards and solid wood the nested approach delivered benefits only when manufactured board was processed in sheets. A machine purchased to produce sheet materials in nests was not as suitable for the solid wood components of the furniture.

The study looked at a range of manufacturing issues that should be addressed when a furniture manufacturer aims at reducing batch sizes and becoming a lean
producer. The way that parts are placed on the CNC machine table was not the only factor when considering more efficient production. The use of a CNC machine capable of processing both sheet materials and solid wood is recommended. A machine capable of removing a large amount of waste is needed to reduce the pre-machining time of the process. Pre-machining is where the part is almost machined to completion before being processed on the CNC machine. The aim is to reduce other processing and get the CNC machine to do a higher percentage of the work at a lower cost.

The smallest batch size is not always the best batch size. It has been shown that in the case of a small batch processing multiple parts in the same cycle with a jig in solid wood; there is no saving in time. The machine movement time will be greater depending on the size of the jig and the jig installation and loading time will add significantly to the production time. In addition; the initial manufacture of the jig, storage and maintenance (of the jig) are significant non-value-adding costs the product will have to bear. In this manufacturing style single parts cannot be produced to replace damaged stock unless a single-machining program is also kept in the database.

### 7.2 Tooling

The use of high-performance tools is highly recommended in order to take advantage of improved (lessened) runout, quick-change tool systems and stacked tooling. The method of applying the tools to the workpiece should also be considered and the focus of observation during the cutting process to establish best practice. Applying the tool in a “power feed” direction may not always be the most ideal in terms of breakout; tool life and power consumption. Low cost tools were investigated but for the removal of large amounts of stock; these are of little use. Tooling is one way to increase the speed of processing and the manufacturer must adopt a high-quality tooling process as part of the overall lean process. Emerging processing and tooling technologies are harder to adopt if the manufacturer does not keep pace with the latest know-how available.
7.3 Best Practice

More efficient ways of processing parts are available to the manufacturer and this has been demonstrated by combining common parts into one processing cycle. A curved, narrow chair leg that will be difficult to hold down with a vacuum jig may be better machined in multiples where a good, strong hold is available; two parts are handled at the same time instead of one and the waste can be efficiently removed from the process. Cutting parameters used on CNC equipment should be observed and altered to better reflect the properties of the wood for splitting and splintering and for excessive loading and potential movement on the CNC machine table leading to inaccurate parts.

The layout of the furniture factory has a direct effect on the material flow and productivity. Large storage areas are needed for large batches but smaller batches require little or no space at all. However in the Australian context, batch size is determined by order size so space is a necessity. The CNC machine must be located in the right position to eliminate as far as possible the time raw materials spend in non-value-adding movements.

7.4 Training

The range of issues identified in Mo et al. (2001) can be improved with training. Manufacturers train on-the-job as required and are usually too busy to set up a structured training system within the workplace. It has been identified that training on CNC machinery in the TAFE system is limited and must be supported with a workplace program that meets the needs of the enterprise. Unskilled workers are able to call up CNC programs, install cutting tools and load and unload work on the CNC machine. Skilled workers are required to investigate the production sequence and put in place best practice for CNC production. There is no reason that a CNC program cannot be called up; the correct tools installed and the production started well within a ten-minute timeframe. If this can be achieved, small batches are possible.
7.5 Specification for CNC Machines Capable of Small Batch Sizes

Rail machines are recommended for small batch sizes of furniture using predominantly solid wood. Rail machines allow the use of stacked tools so more cutting tool profiles can be kept in the tool change magazine. They allow for the heavy cutting of wood thereby reducing the amount of work done on static machines (preparing the wood for the CNC machine). They allow for the quick positioning of vacuum holding devices and the quick turnaround of programs.

Flatbed CNC machines are not recommended for small batch sizes of furniture using predominantly solid wood. The flat table does not normally allow for the use of stacked tools. The flat table takes longer to set up vacuum pods to raise the material sufficiently off the flat table to allow for undercuts as in the case of a lambs-tongue mould. The flat table leaves offcuts that a cutting tool may contact as it moves around the parts, resulting in damage to tools, the workpiece and injury to operators from ejected offcuts. For a company that processes both solid wood and panel materials; a hybrid machine where half the table is flat and half the table is of pod and rail design is recommended.

7.6 Future Research

- The cutting speed (feed speed) of modern tooling is set by the tooling manufacturer (Leitz 2002) and is determined considering the cutting depth and diameter of the tool and by characterizing the wood as softwood or hardwood. These values relate to European woods and do not equate to Australian timbers. Research could identify optimum feed speeds for a range of common Australian timbers and a range of common cutting scenarios. The potential to decrease the cutting time is one of the greatest possibilities to improving CNC machine output in the manufacturing chain.

- The holding of multiple parts in a jig on a CNC machine is a requirement to reduce batch sizes further. It is recommended that further study be
done to determine the required vacuum required for a given number of pieces that occupy a given surface area within the machining table of a CNC machine. The research could look at different materials and jig designs to suggest an algorithm to determine the required vacuum for a range of scenarios.
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Appendix 1 Companies visited during the study

<table>
<thead>
<tr>
<th>Company Name</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aartek Cabinets</td>
<td>Clayton South, Victoria, Australia</td>
</tr>
<tr>
<td>Advance Cabinet Works</td>
<td>Bundoora (Melbourne), Victoria, Australia</td>
</tr>
<tr>
<td>AWG</td>
<td>Bayswater, Victoria, Australia</td>
</tr>
<tr>
<td>Aicher Holzhaus (wood house frames)</td>
<td>Halfing, Germany</td>
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<tr>
<td>A.I.D.I.M.A. (Research)</td>
<td>Valencia, Spain</td>
</tr>
<tr>
<td>Bell's Joinery</td>
<td>Benalla, Victoria, Australia</td>
</tr>
<tr>
<td>British Columbia Inst. Technology</td>
<td>Vancouver, B.C., Canada</td>
</tr>
<tr>
<td>Bern Uni. Applied Sciences (HSB)</td>
<td>Biel, Switzerland</td>
</tr>
<tr>
<td>Carl Hansen &amp; Son (Chairs)</td>
<td>Aarup (Odense), Denmark</td>
</tr>
<tr>
<td>Castlereigh Kitchens</td>
<td>Emu Plains, (Sydney), NSW, Australia</td>
</tr>
<tr>
<td>Choice Cabinets</td>
<td>Fern Tree Gully, Victoria, Australia</td>
</tr>
<tr>
<td>Danish Technological Institute</td>
<td>Odense, Denmark</td>
</tr>
<tr>
<td>Davis Furniture (Solid wood)</td>
<td>Bayswater, Victoria, Australia</td>
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<tr>
<td>Danby Cabinets</td>
<td>Canterbury, Melbourne, Victoria, Australia</td>
</tr>
<tr>
<td>Dreamhaven Furniture (Bedroom)</td>
<td>Thomastown, Victoria, Australia</td>
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<tr>
<td>Dall&quot;Agnese</td>
<td>Brugnera, Italy (Flat panel manufacturer)</td>
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<tr>
<td>F.I.R.A.</td>
<td>(Furniture Research), Stevenage, United Kingdom</td>
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<td>Faschschule Holztechnik</td>
<td>Hildesheim, Germany</td>
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<tr>
<td>Ferrimobili (Children’s furniture)</td>
<td>(Near) Rimini, Italy</td>
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<td>Felder Machinery (Distributor)</td>
<td>Emu Plains (Sydney), Australia</td>
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<tr>
<td>Felder Machinery (Manufacturer)</td>
<td>Hall in Tirol, Austria</td>
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<td>Fine Detail Joinery</td>
<td>Melbourne, Victoria, Australia</td>
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<tr>
<td>Fraubrunnen Mobelfabrik</td>
<td>Fraubrunnen, Switzerland</td>
</tr>
<tr>
<td>Company/Institution</td>
<td>Location</td>
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<td>Fluck Werke (Kinder furniture)</td>
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<td>Gabbett Machinery</td>
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<td>Holzfachschule Bad Wildungen</td>
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<td>Homag (Factory)</td>
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<td>IKEA</td>
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<td>Jayco Caravans</td>
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<td>JK Windows</td>
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<td>Leitz Tooling (Factory)</td>
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<td>Maton Guitars</td>
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<td>Murphy and Langfield</td>
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<td>Naldini Arredamenti (Joinery)</td>
<td>Carpena (Forli) Italy</td>
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<td>Nestle-Fenster (Windows)</td>
<td>Waldachtal, Germany</td>
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<tr>
<td>Nordemann (stairs)</td>
<td>Harsewinkel, Germany</td>
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<td>North Carolina State University</td>
<td>North Carolina, U.S.A.</td>
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<tr>
<td>Orchid Furniture</td>
<td>Kilsyth, Victoria, Australia</td>
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<tr>
<td>Odense Uni. College of Engineering</td>
<td>Odense, Denmark</td>
</tr>
<tr>
<td>Purdue University</td>
<td>West Lafayette, Indiana U.S.A.</td>
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<tr>
<td>Poggenpohl Kitchens</td>
<td>Detmold, Germany</td>
</tr>
<tr>
<td>Posch (Ralf design mobel)</td>
<td>Hall in Tirol, Austria</td>
</tr>
<tr>
<td>Reichert Doors (Solid cabinet doors)</td>
<td>Pfalzgrafenweiler, Germany</td>
</tr>
<tr>
<td>Rosenheim Institute</td>
<td>Rosenheim, Germany</td>
</tr>
<tr>
<td>Savannah College of Art &amp; Design</td>
<td>Savannah, Georgia U.S.A.</td>
</tr>
<tr>
<td>Company Name</td>
<td>Location</td>
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<tr>
<td>SCM Spa. (Machinery manufacturer)</td>
<td>Rimini, Italy</td>
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<tr>
<td>Tessa Furniture (Occasional)</td>
<td>Bayswater, Victoria, Australia</td>
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<tr>
<td>Unifor Spa (Commercial fit outs)</td>
<td>Turate (Como) Italy</td>
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<td>University British Columbia</td>
<td>Vancouver, B.C., Canada</td>
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<td>Victorian Charm (Solid timber)</td>
<td>Mt. Waverley, Victoria, Australia</td>
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<td>Weeke Bohrsysteme (Machinery)</td>
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<td>Thomastown, Victoria, Australia</td>
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<tr>
<td>Yarra Valley Cabinets (Kitchens)</td>
<td>Kilsyth, Victoria, Australia</td>
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</tbody>
</table>
Appendix 2 Recommended tool speeds (Leitz)
Author/s: 
Ashley, Philip Neil

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Date: 
2016

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