The Application of Process Planning in the Irish Furniture and Wood Products Industry

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Dedication

To my wonderful wife Karen.

Our children; Jade, Nathan, Noah, Isabelle and Jonah.

This was, and is, for you all.

Acknowledgements

The creation of this thesis required assistance, in many forms, from many people. Without the help of these brilliant people the completion of this thesis would not have been possible.

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To my wonderful wife Karen. Thank you for all the unconditional love, guidance, and support that you have given me. For never complaining and always understanding, especially when I had to 'go up to the office' again. It is because of your devotion this has materialised. Thank you for everything.

Declaration

I hereby declare that the work presented in this thesis is my own, except where duly acknowledged.

Signed: Paul Leamy
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Date: 8th September 2010

Summary

In its simplest form process planning is the preparation of a list of the sequence of processes, applied to material in a manufacturing facility, to bring it to a useable part or product. Process planning can be seen as an integral component of the design-to-manufacture cycle. There is a shortage of available research and other supporting material relevant to the design-to-manufacture cycle in the furniture and wood products industry. This shortage is more acute in the context of the major changes in production technology that have overtaken the industry in the last 20 years, predominantly flexible computer numerical controlled (CNC) machining centres.

Even though CNC technology is abundant in the Irish furniture and wood products industry, companies were not utilising it to full potential. This feedback led the research work towards looking specifically at the application of process planning methods. The practice of process planning is common in other manufacturing industries as are the benefits. Research conducted in this project found no evidence of any formal process planning being used in the Irish furniture and wood products industry. Further study revealed that the decision to make a component on a particular machine was based on the decision makers training, experience and personal preferences, and not based on any calculation of the most productive method.

Thus the primary objective of this thesis became the development of a methodology for process planning that will support product engineering efforts, and guide design and production decisions involving traditional and modern technology.

Results from workshop based process planning trials, revealed extraordinary differences in experienced people's process plans, for the manufacture of the same product in the same manufacturing facility. Process planning decisions were found to be influenced by peoples experiences with certain processes and not based on any formal thought process as to the most economical solution.

Process planning guidelines were developed for a limited number of woodworking processes. These guidelines were applied in a sample exercise using intelligent spreadsheet logic with a range of process and part parameters and a knowledge base of previously recorded set-up and processing times. They achieved more favourable results than any of the eight process planners involved in the trials.

The guidelines were then integrated into a process planning methodology to demonstrate how such a decision tool might be utilised in a larger product development approach. Finally, a list of functionality is given for a process planning decision support system based on the results of the research.

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Glossary of Terms and Abbreviations

AI	Artificial Intelligence
BOM	Bill of Materials
CAD	Computer Aided Design
CAD/CAM	Computer Aided Design/ Computer Aided Manufacture
CAPP	Computer Aided Process Planning
CNC	Computerised Numerical Control
DFM	Design for Manufacture
ERP	Enterprise Resource Planning
FWP	Furniture and Wood Products
FWPI	Furniture and Wood Products Industry
FMEA	Failure Modes and Effects Analysis
FMS	Flexible Manufacturing System
GMIT	Galway-Mayo Institute of Technology
Groove	A groove cut into timber along the grain
Housing	A groove cut into timber across the grain
KD Fitting	Knock Down Fitting
MDF	Medium Density Fibreboard
PDM	Product Data Management
PDS	Product Design Specifications
PP	Process Planning
QFD	Quality Functional Deployment
R&D	Research and Development
Rebate	An open groove cut into the edge of material
Stopped Groove	A groove that does not continue the full length of the work piece
SME's	Small To Medium Sized Enterprises
Through Groove	Continuous groove the full length of the workpiece
VA	Value Analysis

1. Introduction

1.1 Statement of Thesis

The author's particular interest in product development stemmed from work and academic experiences applying design for manufacture (DFM) principles and associated techniques to furniture and related products. A shortage of available research and other supporting material relevant to the application of product development techniques in the furniture and wood products industry hampered progress and understanding. Thus a resolve emerged to research and develop the understanding and application of product engineering methods in the furniture and wood products industry. This shortage is more acute in the context of the major changes in production technology that have overtaken the industry in the last 20 years most notably flexible Computer Numerical Control (CNC) machining centres.

Initial literature investigation revealed a lack of product development practice in the industry. Also it appeared that, even though CNC technology is abundant in the Irish furniture industry, companies seemed not to be utilising it to its full potential. This feedback led the research work towards looking specifically at the application of process planning methods to assist furniture and wood product companies to take best advantage of new technologies.

Therefore the overall objective of this thesis is to provide a process planning methodology, focused on flexible CNC machining centres and alternative traditional machines, to guide companies in their design to manufacture cycle.

1.2 Background

The author of this thesis, his research supervisor and many work colleagues are heavily involved in the furniture and wood products manufacturing industry. They are particularly involved in the provision of education for people in and entering the industry and are deeply interested in design, production and management methods and technologies that can change and improve the industry.

The author's interest in re-engineering complicated furniture and wood products, essentially designing for manufacture, is what initiated research work into this subject. At an early stage it became evident that there was a shortage of available research data relevant to product development techniques in the furniture and wood products industry. This seemed to contradict the enormous growth in the application of production technology that the industry has witnessed in the last 20 years. This has seen the industry change from mainly a craft or trades led industry to a technology orientated industry.

Thus a resolve emerged to research and develop the understanding and application of product engineering methods in the furniture and wood products industry. Initial investigation revealed a lack of product development practice in the industry. Also it appeared that, even though CNC technology is abundant in the Irish furniture industry, companies seemed not to be utilising it to full potential. Companies with and without CNC machinery were winning and completing considerable contracts. This feedback led the research work towards process planning to assist furniture and wood product companies to take best advantage of new technologies. An effective process planning methodology could have the dual effect of contributing to product development and to higher utilisation of expensive CNC technology.

1.2.1 Recent changes in industry production capabilities

In the mid 1980's and on into the 90's many Irish furniture and wood products SME's (small to medium sized enterprises) invested in 3-axis machining centres without fully understanding the technology, how to adapt their products to best utilise this new technology, the capabilities, the process planning requirements, and the scale of the parallel investment required in training, personnel, and software (Tobin, 2002). In the late 1990's, according to McFerran et al (1999), furniture SME's had the lowest average percentage return on assets of any SME sector, reinforcing the commonly held view that they were under utilising these expensive CNC machines. It has taken many years for some of these companies to adapt, and others are still trying to. It is important to note that observations like these about the industry in Ireland are largely anecdotal, as there is very little up to date research data available. One of the most useful sources of up to date information about the industry has been the reports produced by Letterfrack BSc students involved in co-operative industrial placements.

In recent years we have seen growth in the acquisition of 5 axis CNC machining technology in the Irish furniture and wood products industry. These machines possess the ability to manufacture 3D components, which removes many restrictions on product design. They can also allow companies to bypass a certain amount of expensive jig manufacture in the production of 2D components.

Based on the co-operative placement reports, the cohort of students from Letterfrack has gone from zero contact with 5-axis CNC in the industry in 2005 to 25% contact in 2009. There is almost 70% contact with 3-axis CNC technology.

1.3 Research Objectives

Almost every report on the Irish furniture industry over the last 30 years has lamented the lack of design and product development effort. The Industry Task Force (1988) commented "*The majority of Irish Furniture Manufacturers do not employ a designer ... Irish manufacturers find it difficult to justify the cost of a designer in comparison with the low to zero cost of their present expedient of copying*." Five years later Kelly (1993) commented that "*The use of designers in the Irish furniture industry is almost non-existent. Most manufacturers see the costs involved in product development as unnecessary and certainly do not regard it as an investment*". McGrath et al (1997) noted "*There are particularly poor levels of design and innovation in the industry*" and "*We have to plug the gaps in terms of developing products and creating brands*."

The above comments are even more disappointing when considered in light of McFerran et al's (1999) performance assessment of the Irish furniture industry. They found that product development as a business strategy was more important for furniture firms than for small firms in other sectors. However, it was not being deployed to any significant extent. In the last ten years the industry has gone through dramatic (but undocumented) changes. Product development was almost extinct during the massive economic activity from 2000 to 2008 because most companies moved to project-based manufacture, responding to the construction market needs for bespoke furniture, joinery and other wood products. In the last two years, suddenly these companies are interested in product development again because they now are seeking new markets to replace the lost construction-related business.

The language of industry has changed to 'Research and Development' (R&D) and 'Innovation'. The furniture and wood products industry has been criticised for a lack of action and use of best practice techniques in R&D and Innovation (Enterprise Ireland, 2004). It is likely, based on these observations, that product development tools and techniques such as concurrent engineering (Hurst, 1993), design for manufacture and assembly (Boothroyd & Dewhurst, 1985), value engineering, quality function deployment (Clausing & Houser, 1988) and others, are not being applied to any great extent in the Irish furniture and wood products industry. These are valuable and proven techniques that should be part of product development initiatives in the industry.

Initial Research Objective – Improve understanding of product development work in practice in the Irish furniture and wood products industry, and determine if formal design methods, particularly Design for Manufacture, Product Engineering and, by association, Process Planning techniques are being applied.

Design for manufacture and product engineering should be part of an effective product development process. 'Product engineering' encompasses the use of a variety of engineering techniques and tools, Research by Tobin (2002) indicates that the industry has moved away from production based on traditional skills and towards technology driven production, ideal for product engineering applications. McGrath et al (1997) highlighted the increased use of Computer Aided Design (CAD) and CNC technology, and also identified the increased interest and activity in the area of new product development in all sectors of the industry. Thus, in any one woodworking company the numerous traditional processing options are supplemented by modern CNC options.

Given the design specifications of an item which has to be manufactured, process planning is the act of generating an ordered sequence of the manufacturing operations necessary to produce that part within the available manufacturing facility, and produce it economically and competitively (Burgess, 1994) (Park, 2002). If process planning is the place where the final 'economic and competitive' method of manufacture is decided; should we consider using it earlier in the design cycle perhaps incorporating process planning as a tool in DFM?

However, according to Burgess (1994) traditionally, process planning has been regarded as a manual operation, usually carried out by qualified and experienced tradesmen with minimal additional training. The success rate achieved by an individual planner is largely dependent upon his individual skill and aptitude for the planning task, his knowledge of manufacturing processes, equipment, materials and methods in general, and those available in his own production facility in particular.

When you consider that process planning involves the preparation of a plan that outlines the operations, routes, machines, jigs, tools and parameters required to transform the materials and/or parts into finished products, it can become very complicated when more processing options are available, particularly when some of those options involve CNC versus traditional processes. These traditional processes might include the spindle moulder, hand router, overhead router, table router, and basic drilling machines.

Expecting traditional tradesman to carry out effective process planning in modern flexible manufacturing environments, with shifting bottlenecks, may be a lot to ask. Although a 3rd level graduate with both practical woodworking and computer/CNC skills and experience may be more likely to deliver good results. Also, if process planning is regarded as being simply a manufacturing task, the potential DFM benefits may be lost. Thus, the creation of a process planning or process decision making methodology that spans and transcends the design-to-manufacture cycle is the primary objective of this thesis.

> **Primary objective** – Develop a formal methodology for process planning that will support product engineering efforts, and guide design and production decisions involving traditional and modern technology

The tasks identified to deliver on this objective include

- The examination of a small sample of traditional processes and comparative CNC processes, and the current process planning practice
- Compare/evaluate processing options based on features, materials, volumes, tooling, jigs, etc.
- Examine process planning research to establish current practice

- Develop and document a process decision/planning methodology that would be a central part of the design-to-manufacture cycle

- This methodology would allow manufacturers to make design and production decisions involving products utilising traditional versus CNC processes. It would also help manufacturers achieve higher utilisation of capabilities and capacity of CNC technology.

- At this point it is worth noting that Gecevska and Cus (2010) claim that process planning is one of the key activities for product design and manufacturing. "*The impact of process plans on all phases of product design and manufacture requires high level of interaction of different activities and close integration of them into a coherent system.*" They recently developed a process model of product development with the manufacturing approach based on intelligent process planning techniques.

1.4 Scope of Research

The research and results are focused on the Irish Furniture and Wood Products (FWP) sector. The application of DFM and particularly process planning appear to be well developed in other sectors, particularly the metal working or engineering sector. Lessons learned from this sector will be included in the research; however issues particular to the FWP industry will be the main focus of attention.

The reasons why the FWP industry may not be as advanced in its application of DFM and process planning as for example the metal working industry, is beyond the scope of this study. Initial research tasks are to simply confirm assumptions about the lack of use of formal DFM techniques in this sector, before focusing on the technical issues involved in process planning.

Furthermore, a limited number of processes and machines are selected for experimentation and trials so that results can be generated within a reasonable time frame. Thus, the results of the study are limited to specific processes and machines. However, the issues and treatment of the issues may be applied to a broader range of processes and machines in future applications.

1.5 Research Methodology

A broad assortment of research methodology is available to the researcher (Creswell, 2003). Selecting the most appropriate methodology depends to a large extent on the type of research being carried out. The research techniques employed in this project included;

- Literature survey and review
- Industry survey (using co-operative work placement reports)
- Case studies
- Prototyping
- Workshop based process planning trials

A literature review was initially conducted in the areas of Product Development, Design for Manufacture (DFM) and Process Planning (PP). Similarly, a review of available reports on the industry in Ireland was conducted. A review of 48 student placement reports selected from over 200 placements of students on the B.Sc. programmes at GMIT Letterfrack from the last 5 years was undertaken. The reports were selected based on being of sufficient academic quality. These reports coupled with interviews with many academic supervisors, generated information about the product development efforts, and technology utilisation. This rich source of information was preferred to a focused survey because of advice that companies in the industry are quite secretive about information and generally unhelpful with data intensive surveys.

A number of companies were selected for further exploration to highlight design issues involving the use of CNC technology. Workshop based research work involved the process planning and manufacturing of a number of products using traditional and CNC machinery, collecting process data from these trials, reviewing the product design and manufacturing issues and analysis of data to help develop a process planning methodology. The sequence of research activities flowed as follows:

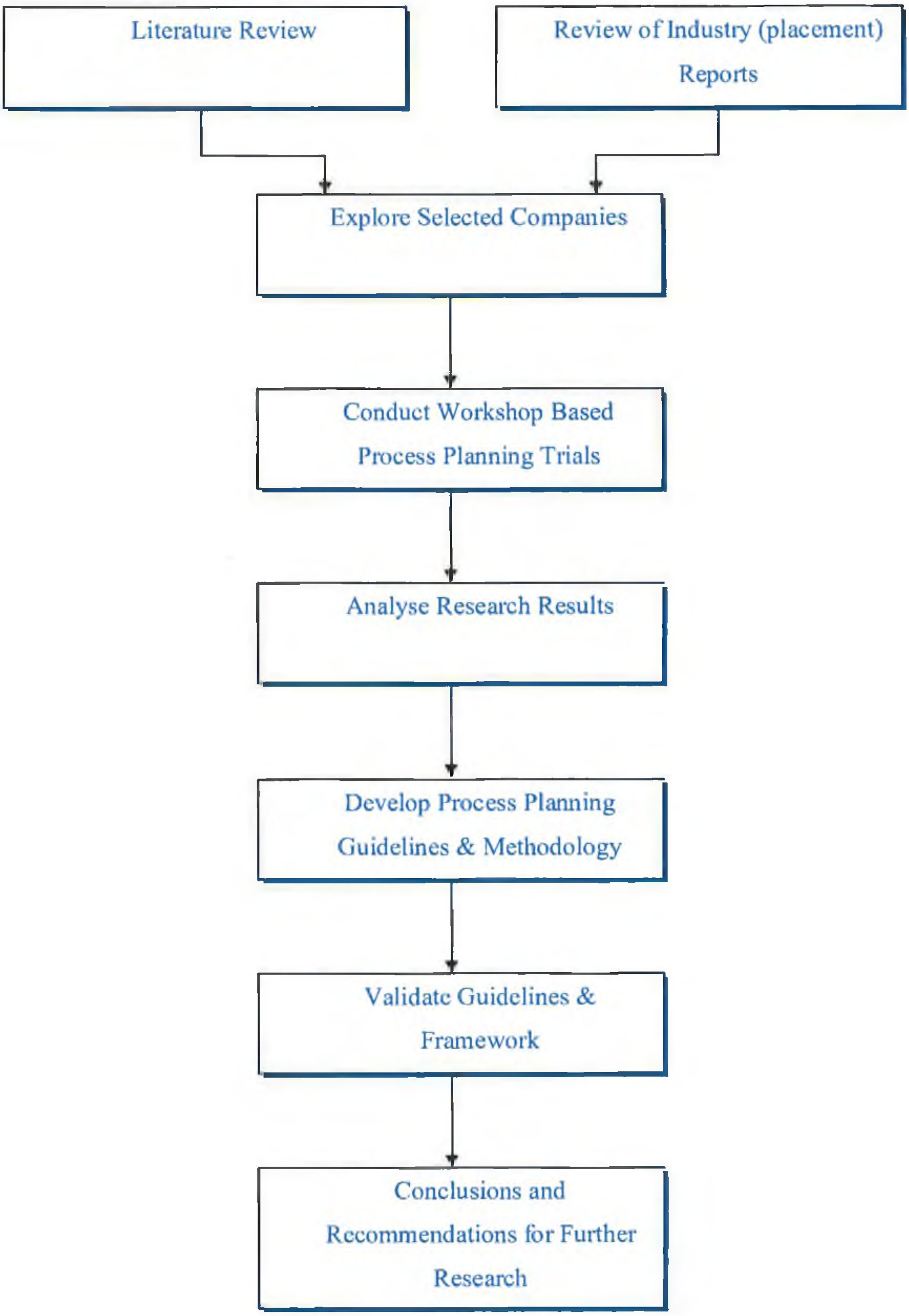

FIGURE 1.1 SEQUENCE OF RESEARCH ACTIVITIES

1.6 Conclusion

This chapter has given the initial background to the development of this thesis. The research objectives were outlined and most importantly the primary objective which is – to develop a formal methodology for process planning that will support product engineering efforts, and guide design and production decisions involving traditional and modern technology.

The scope of the research has been documented along with the research methodology employed during the course of this research. The following chapter looks at process planning and the design-to-manufacture cycle.

2 Processing Planning & the Design-to-Manufacture Cycle

2.1 Introduction

In order to manufacture any given product, someone has to put some thought into the design of that product. Even if the product is very simple and basic, and requires only an informal concept, there is still a design process before manufacture. When one has a product design, one must also have given some thought to actual materials and processes required to make the product before manufacture can commence. Again, this can be very informal, even as simple as some thoughts by a machinist before commencing manufacture.

However, in many manufacturing industries, detailed product designs, materials requirements and process plans would be formalised before manufacture. The purpose of this chapter is to examine the design-to-manufacture cycle, sometimes called the product development process, and explore approaches to process planning.

This chapter discusses the contributions from the literature on process planning, design for manufacture and the design-to manufacture cycle. The chapter also presents a view of the Irish furniture and wood products industry in order to provide a context for the research actions in the following chapters.

2.2 Design to Manufacture Cycle

There are many variations of the product development process, or design-to-manufacture cycle, available. Comparing the relative merits of some of these methodologies is not within the scope of this thesis. However, it is important to describe one method in order to illustrate where the design for manufacture techniques are applied and more importantly where production process choices/decisions /constraints are introduced to the design-manufacture cycle.

The 'Total Design' methodology developed by Stuart Pugh (1991) has been used in product development projects in GMIT Letterfrack since 1996. Pugh's approach can be viewed as five stages (six if 'selling' is included)

- Market / Customer Requirements
- Product Design Specifications
- Concepts
- Detail Design
- Manufacture

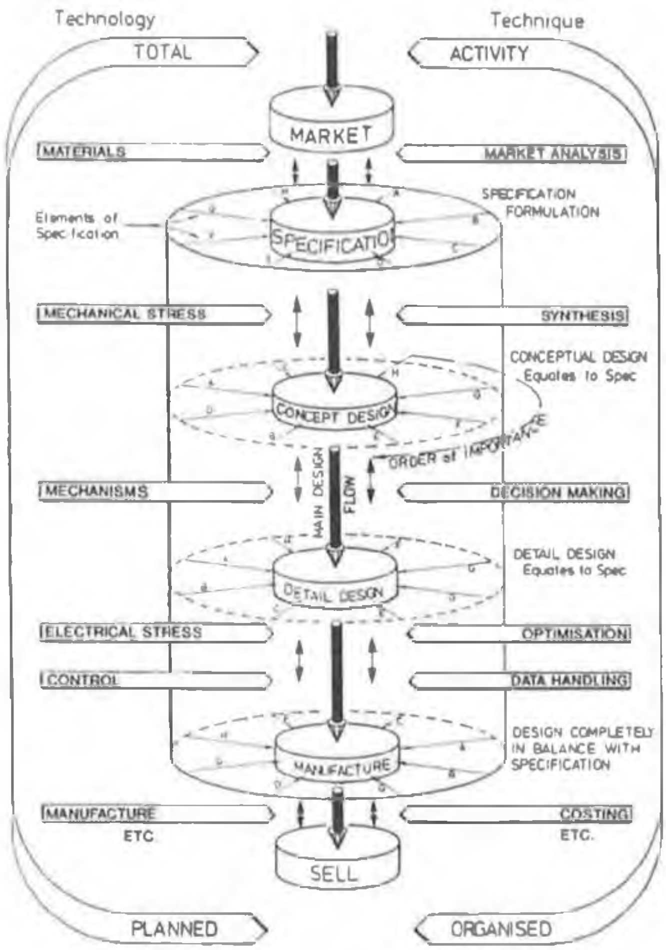

FIGURE 2.1 TOTAL DESIGN ACTIVITIES (PUGH, 1991)

At each of these stages design 'decisions' or 'choices' are made. With progress through the stages the decisions become more focused and concrete. Associated with the design decisions at each stage are processing implications, constraints, choices or decisions. Again they become more specific and concrete with progress, culminating in final process plans before manufacture. In Pugh's model formal DFM analysis is conducted at the detail design stage. Pugh also allows for regression to a previous stage if the outcomes of any activity suggest revisions of previous decisions.

Peter Scallan (2003) sets the context for his discussion of process planning by defining the "Design and Manufacture Cycle". Scallan's model relies heavily on Pugh's work and verifies the use of this approach in this analysis of DFM and process planning.

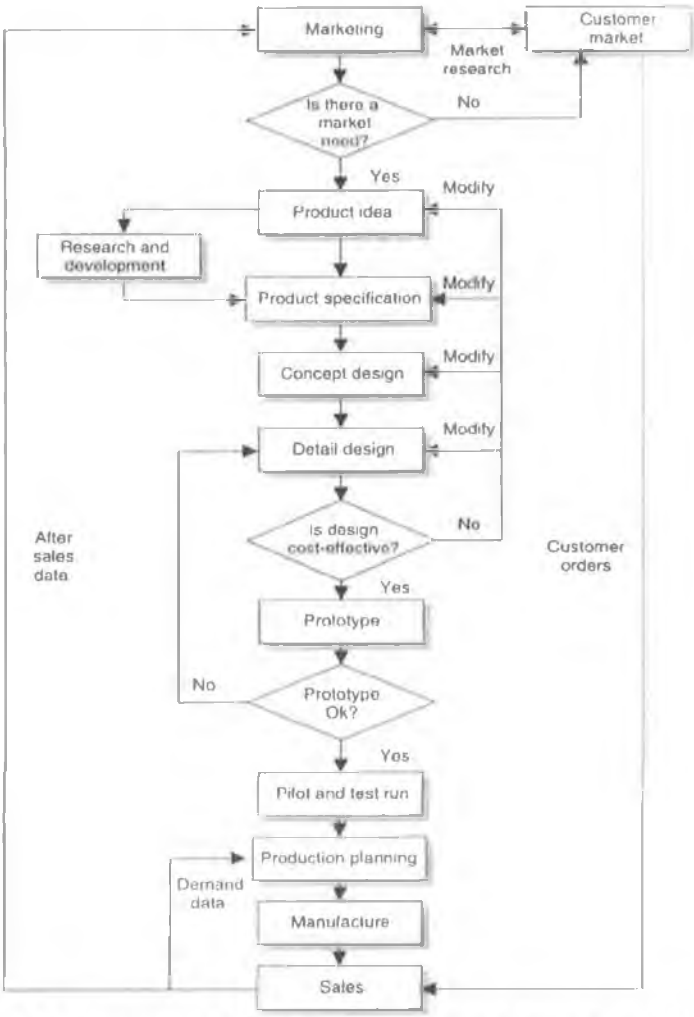

FIGURE 2.2 DESIGN AND MANUFACTURE CYCLE (SCALLAN, 2003)

2.2.1 Design for Manufacture

Design for Manufacture (DFM) consists of a collection of methodologies and techniques and can mean different things to different people. DFM approaches were popularised in the late 1980's by people like Stoll (1986) and Boothroyd & Dewhurst (1988). They became an integral part of product design methodologies such as 'Total Design' (Pugh, 1991)

Stoll (1986) provided a set of DFM principles and rules as follows:

1. Minimise total number of parts

This means less:

- components required
- engineering time
- drawings
- production records
- inventory
- purchase orders's
- material handling & material handling equipment
- accounting details
- service parts
- items requiring inspection
- complexity of production and facilities
- assembly
- training

In other words, a part that is eliminated costs nothing to make, assemble, move, handle, store, purchase, clean, inspect, service or rework. However, part reduction should not exceed the point of diminishing return where further part reduction adds cost or complexity, i.e. the remaining parts are too heavy or complicated to make or assemble or are unmanageable.

2. Develop a modular design

It offers the ability to standardise diversity as it allows a product to be customised by using different combinations of standard components.

3. Use standard components

A stock item is always less expensive than a custom-made item. Stock items are well known and therefore so are their abilities and weaknesses. Also replacements are easier to find if required. It puts some of the burden back on the supplier.

4. Design parts to be multi-functional

Combine functions wherever possible, for example a leg for a desk incorporating cable management rather than 2 separate solutions.

5. Design parts for multi-use

For example the same mounting plate can be designed to mount a variety of components for a variety of products. 2 main categories: parts that are unique to a certain product, and parts that are required in all products.

6. Design parts for ease of fabrication

Parts should be designed using the least costly material that satisfies the functional requirements. Avoid secondary processing like finishing. However, a higher material and/or process cost may lead to an overall lower production cost.

7. Minimise assembly directions

Parts should be assembled from one direction. Extra directions mean wasted time, motion, transfer stations, more equipment, etc. Ideally assembly should be top down in relation to the piece.

8. Maximise compliance

Rather than tight fitting components allow some tolerance to avoid delays. The same parts will have variance from one to the other. If parts won't fit, it can delay the system.

These guidelines are very useful as a checklist or questionnaire to evaluate concepts and early designs and to support design changes. The guidelines are usually applied in conjunctions with other analytical techniques. A number of product engineering techniques such as Quality Function Deployment (QFD), Value Analysis (VA), and Failure Modes and Effects Analysis (FMEA) are sometimes included as part of the DFM approach (Brown et al., 1989).

Later research, from Poolton & Barclay (1998), showed that "*Developing products in line with technical production capability is one of the major issues associated with successful product development*". Poolton and Barclay (1998) associate success with products that capitalise on in-house technology, engineering skills and manufacturing expertise. They refer to research that shows that 'Step-out' projects that lack synergy with in-house capabilities have failure rates of around 77% compared to failure rates of 18% for projects that are closely coupled to technical and manufacturing capability.

Riedel et al (1997) argue that 'production aspects' should be considered at all product design stages, not just when the design moves closer to production. They noted in their study that *"The most important production aspects considered in the conception design stage were product cost, development cost, functional requirements and materials. The balance of attention firmly shifted to production aspects in the prototype stage. Labour requirements and production control were the most significant production aspects considered. The prototype stage was the most important for the consideration of production aspects, considering all production aspects - how to make the product, by what means and by whom. Pre-production was devoted to refining how to make the product. This shows that the manufacturability of the product is not considered until after it is designed."*

Riedel et al (1997) observed that production engineering was more extensively involved in the design process the closer it moved towards manufacture. They concluded that this was too late to include production engineering knowledge into a product's design. They recommended that companies should endeavour to consider the production aspects of machinery, labour requirements and plant in the detailed design phase. They also found scope for production to be considered in the conceptual design stage, and at the specification of the product stage.

2.3 Process Planning

How does one design a part for manufacture without thinking about the manufacturing process? If you are thinking about a specific manufacturing process while designing the part, have you already partially decided on the best process plan? If you introduce constraints at different stages of the design cycle do these constraints contain implicit process choices? Do these choices constrain the process plan? These are questions that troubled the author and led to further investigation, beginning with a look at the definition of process planning.

According to Rembold et al (1996), process planning involves the act of preparing a plan which outlines the operations, routes, machine tools, fixtures, tools, and parameters required to transform a part or parts into a finished product. They claim that the 'pure' process planning activity has no time element associated with it, but that the manufacturing scheduling element does. However, within the context of this research the author would consider 'time' (taken to process the part) an important factor of process planning, and a significant parameter when it comes to making a decision between process choices.

A 'narrower' description of process planning (Chang & Wysk, 1985) involves the translation of design data to work instructions to produce a part of a product. The so-called process planner would use the information presented on the engineering drawing and the bill of materials (BOM) in the generation of an executable plan. This view however, does not allow for the inherent process planning decisions contained in an engineering drawing or BOM.

"*The Society of Manufacturing Engineers defines process planning as the systematic determination of the methods by which a product is to be manufactured, economically and competitively*." (Tulkoff, J. 1988). This definition is similar to Park (2002) and not as restrictive as some others and gives the process planner some opportunity to get involved in earlier design stages and influence the design. However, Zeid & Ibrahim (1991), and Burgess (1994) stick to the narrower definition involving:

- the conversion of design data to manufacturing or work instructions
- the activity that translates part design specifications from an engineering drawing into the manufacturing operation instructions
- the act of generating an ordered sequence of the manufacturing operations necessary to produce that part within the available manufacturing facility

Chang and Wysk (1985) argue that the process planner must possess the following knowledge:

- ability to interpret working drawings,
- knowledge of manufacturing processes and practices,
- knowledge of tooling and fixtures,
- knowledge of the factory's available resources,
- knowledge of how to use reference books, such as data handbooks,
- knowledge of how to perform operation time and cost analyses,
- knowledge of raw materials,
- knowledge of the relative costs of processes, tooling and raw materials.

Scallan (2003) draws on the above skills and describes in great depth the skills and tasks associated with the process planner:

- Drawing interpretation
- Material evaluation and process selection
- Selection of machines and tooling
- Setting process parameters
- Work-holding devices
- Selecting quality assurance methods
- Costing
- Preparing the process planning documentation

Consider the benefits if such a 'process planner' were involved in the earlier design stages and not just manufacture. Much wasted time and costly trials and errors could be avoided. Furthermore, consider the benefits if the experience and knowledge of such a planner was captured in a decision support system.

As mentioned earlier Burgess, (1984), describes process planning as a manual process carried out by qualified tradesmen. He claimed the success rate achieved by a planner was dependent on his knowledge of equipment, materials and methods in general and especially those in own facility. Scallan (2003) concurs with this assessment, commenting that it was usually the manufacturing foreman that would take the drawings and determine the best way to manufacture the part, based on the workforce skills and machinery at their disposal. However, Scallan believes that now most organisations have a formal method of process planning. This belief is challenged in the furniture and wood products industry in the next chapter.

According to the Society of Manufacturing Engineers (1988) process planners are knowledge workers, dealing exclusively with information to establish the orderly and efficient instructions for manufacture and assembly. "*Process planning requires intimate knowledge of manufacturing processes like machining, shaping, and finishing, in addition to familiarity with the production capabilities of the plant in which a product is being manufactured. Process planning is the key interface with product design, thus being the lead activity within the manufacturing plant in the general flow of information from product design to the factory floor.*"

Scallan (2003) outlines a formal manual process planning approach and some general guidelines. He suggests that the process planning tasks should commence with the part drawings, and should be supplemented by workbooks containing pre-determined sequences of operations for given types of work-pieces. Scallan's general guidelines are:

- Establish one datum as soon processing commences and use it as a reference for all subsequent operations
- Create as many surfaces as possible at the same setting (i.e. without clamping and unclamping) to maximise dimensional accuracy
- Avoid the use of secondary surface data as much as possible
- Precision operations, for example, those producing high quality surface finishes, should be carried out last to reduce the possibility of damage
- Inspection operations should be included at appropriate intervals to minimise scrap and rework

The final finished process plan is a set of instructions specifying how the product should be manufactured, including the sequence of machines tools required, and the setting for each machine. Askin and Standridge (1993) show in figure 2.3 a generic process plan. Each row contains the information the worker requires to manufacture the part.

Part Name Shaft
Part No. AS34967
Planner John Doe
Date 9/11/90
Sheet 1 of 1

Department	Machine	Operation No.	Operation Description	Tool Name	Tool No.	Setup Time	Unit Time
120	Drill Press	100	Drill Cross Hole, 3/8"	Bit Fixture	D1415 P 967	.10 hrs	.002
120	Vert Mill	110	Mill Front Face	End Mill Fixture	GC111 S 3641	.15 hrs	.001
120	Lathe	120	Turn O.D. 1.540" ± .001	Cutter Fixture	HS 340 LC 967	.20 hrs	.014
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

FIGURE 2.3 TYPICAL PROCESS PLAN FORMAT. (ASKIN & STANDRIDGE, 1993)

Scallan (2003) lists some disadvantages associated with manual process planning, including

- Excessive clerical content
- Lack of consistency in planning
- Late design modifications
- Changing technology

He suggests that Computer Aided Process Planning (CAPP) systems have developed in response to these disadvantages.

"*Process planning translates design information into the process steps and instructions to efficiently and effectively manufacture products. As the design process is supported by many computer-aided tools, computer-aided process planning (CAPP) has evolved to simplify and improve process planning and achieve more effective use of manufacturing resources*." (Crow, 2005)

Crow (2005) describes manual process planning as being based on a manufacturing engineer's experience and knowledge of production facilities, equipment, their capabilities, processes, and tooling. He also points out that it is very time-consuming and the results vary based on the person doing the planning.

The evolution from manual to computerised process planning is described succinctly by Crow (2005). Initial standardised plans for part families on spreadsheets or databases, evolved into "variant" CAPP based on group technology (GT) coding and classification. Further development led to "generative" CAPP systems that utilise decision rules based on the part's GT parameters. A true generative system would use part classification and design data, together with capacity and live workload data, resource status data and tooling availability. Thus a process plan could vary depending on the current workload and resource status.

Crow (2005) points out that, 'variant' process planning is relatively straightforward. A code is matched with a standard process plan. However, there is a lot of effort in developing the GT classification and coding structure for the part families and in manually developing a standard baseline process plan for each part family. The important element of a generative system is the development of decision rules appropriate for the items to be processed. The nature of the parts affects the complexity of the decision rules for generative planning. According to Crow (2005) the majority of generative CAPP systems implemented to date have focused on process planning for fabrication of sheet metal parts and less complex machined parts. Crow (2005) describes an approach to generative planning driven by features technology (FT) type classification without a numeric code. This would involve a user responding to a series of questions about a part that in essence capture the same information as in a GT or FT code.

According to Burgess (1984), given the need for significant improvements in the process planning process, the complexity of the data and technological relationships makes it essential to utilise more sophisticated computer techniques to make a significant improvement in process planning based on generative process planning methods.

2.4 Systems for Process planning

While there is much academic literature about CAPP, particularly related to the engineering industry, examples of true CAPP systems in the wood products industry are not easy to find. Searches on trade websites such as Manufacturing Computer Solutions (www.mcsolutions.co.uk) come up with inconclusive results. One finds ERP systems, computer aided design/computer aid manufacture (CAD/CAM) systems, and estimating systems that all claim to have CAPP functionality. Further analysis usually leads to some form of process listing or sequencing module. For example, ERP systems like MS Dynamics NAV, Syspro and SAP have modules that allow the user to build process routings linked to particular machines and enter data on setup and processing time etc. Some allow the user to specify alternative routings. However, there is no mention in their literature of decision support. Both Syspro and MS Dynamics NAV have been used as ERP lab-systems in GMIT Letterfrack and neither had any intelligent functionality to support process planning.

In the late eighties and early nineties there was a considerable research focus on expert systems for computer aided process planning. Chu and Wang (1988) reviewed available systems and proposed a framework for the application of artificial intelligence in process planning. Gupta and Ghosh (1989) also surveyed available systems and discussed popular approaches. The author has conducted numerous searches to find commercial systems that use artificial intelligence (AI), without success. Even systems that use group technology classification type approaches to decision support are hard to find.

In 2008 Pro-Engineer (Pro-E) added process planning functionality to its 'Windchill' software, which allowed users to create a "process plan" for a part including data on the operations to be performed, the standard processes used to perform these operations, the sequence in which they must be done, the parts related to the operation, and the physical and human resources required to complete the operation. Included in the Pro-E process plan are any document references or descriptions that could aid the worker, and a process plan can be used to evaluate time and cost requirements. However, there is no mention of decision support regarding alternative plans or processing choices. Other CAD packages like Solid Works also include so-called process planning features through their Product Data Management (PDM) functionality. But again they behave like straight forward flat databases.

A study from Humm et al (1991), regarding the use of previous process plans in a knowledge-base, showed some possibilities for practical application. This study claimed to integrate generative and case-based planning methods. The knowledge-base was dynamic, containing previous cases i.e. part descriptions and corresponding process plans. "*This knowledge base grows with experience and ... enables automated improvement of similarity metrics which can be regarded as learning*". This type of approach is appealing because it allows the users to build a sophisticated knowledge base with operation specific guidelines or rules over a period of time. This option will be further investigated in chapter 4.

2.5 Design for Manufacture & Process Planning in the Metal Industry

There are many examples of process planning being applied in the metal Industry, (Duflou et al (2005), Nelson & Schneider (2001)). The techniques seem to be accepted and used extensively. Interestingly, there are also indications that researchers in this industry have looked beyond the use of process planning at the end of the design to manufacture cycle. Hodgson & Pitts (1991) suggested that a radical approach be adopted at the front end of the manufacturing process, which is at the design stage, when the possible savings could be enormous. "*It is well documented that the majority of costs are determined at the design stage so that no matter how good the jig and tool designer, the production engineer and all the other production support people, the fact remains that they can influence final production costs only minimally.*"

Hodgson & Pitts (1991) addressed the metal removal sector of the manufacturing industry, and targeted basic 3-axis CNC machine tools. They proposed to seek alternatives to the vogue at the time of placing great emphasis on the manufacturing-led solutions, (i.e. Flexible Manufacturing Systems) and to make better use of stand-alone computer numerical-controlled, CNC, machine tools. They proposed that the designer should aim to achieve either:

(a) a single set-up on a machine tool, using one tool;
(b) a single set-up on a machine tool, using the minimum number of tools;
(c) the minimum number of set-ups on the same machine tool;
(d) the minimum number of transfers between different machine tools.

Rules (c) and (d) recognize that not every component can be designed for single-set-up manufacture and therefore traditional design strategies have to be allowed. These observations and proposals are significant in terms of the wood products industry and will be a key factor in the research described later.

Hodgson & Pitts (1991) originally intended to examine as many designs as possible to cover a wide field of the engineering industry but they soon realised that tackling the project objective by taking the components, as designed, and refining the design was not going to be successful. "*As an alternative approach the design was started again from the concept stage using the original requirement specification. The result of the revised design was that the 'new' components rarely looked anything like those they replaced. The techniques developed in the project permit details to be designed for single-set-up manufacture. Taken singly they may appear simple or even trivial. Taken together they could form a powerful contribution in reducing product costs.*" Hodgson & Pitts (1991). This conclusion also has significance for wood products designers, and will be addressed in later sections.

2.6 The Furniture and Wood Products Industry

The Irish furniture and wood products industry is often just termed the 'furniture industry' because the scope of the term 'furniture' appears to have broader application in Ireland than elsewhere. It is made up of a variety of sub-sectors, and unfortunately no standard set of descriptions has been adopted in the labelling of these sub-sectors. The most recent industry surveys use terms such as 'domestic furniture', 'contract office furniture', 'hotel furniture', and 'contract fitted furniture'. Other sub-sector labels used in the past have included 'fitted kitchens and bedrooms', 'components', 'architectural joinery', 'soft furniture' and others. Sometimes segmentation has been addressed on the basis of the primary materials, e.g. metal, hardwoods, manufactured board, or by primary production processes, e.g. panel production, upholstery, solid wood. McGrath et al (1998) note that the furniture sector in Ireland is quite 'heterogeneous', consisting of a wide range of different categories each producing different products.

Thus, the Irish furniture industry is quite varied and fragmented. Bulow (1996) noted the absence of reliable data on all aspects of the industry. A recent survey conducted by GMIT Letterfrack 4th year B.Sc. degree student Roisin Kilraine concluded that average company size was 12 employees, based on a sample of 61 companies. This compares with claims of an average of 19 employees by Heanue (2006), which is not very different from Kelly (1995) and McGrath et al, (1998) who claimed the average company size to be 17-18 employees.

Because of the lack of definition of the market, statistics on sales, imports and exports are at best a guideline. It is difficult to compare like with like because the delineation of sub-sectors is not always clear, nor are the facts behind the information. For example, some of the figures used in calculating market size might be based on retail sales values, while the figures used in calculating production output might be ex-factory prices. In the 2004 Enterprise Ireland Yearbook, Burke writes about the furniture industry "*industry commentators say that analyses within the sector need finer definitions - for instance, what is furniture, and what is not? Different reports are said to give widely varying statistics on such things as employment, profitability, sales and competitiveness because of the lack of clear definitions*."

After reviewing a selection of reports published over the last 30 years, it is disconcerting to note that many of the weaknesses of the industry being identified are still the same, and some of the warnings are materialising. Of most interest is the recurring issue of the lack of management skills in design, and product development. Of interest also is a recurring strength in the area of production technology. The Irish industry has consistently been recognised as being well equipped in terms of production technology. (ITF, 1988) (InterTradeIreland, 2000), (McFerran et al, 1999) (Bulow, 1996)

InterTradeIreland, (2000), noted that furniture companies in Ireland range from small cottage industries to large fully automated manufacturing facilities. McFerran et al (1999) highlighted the importance of small firms and particularly the predominance of family-owned businesses in the industry. Bulow (1996) also draws attention to the fact that many companies are family owned and managed enterprises. He also points out many firms operate both Joinery and Furniture workshops. There have not been any more recent reports that investigate this point, but anecdotal evidence indicates that Irish furniture manufacturing companies are very flexible, and can produce a wide variety of products. Many are project-based manufacturing companies and are regularly dealing with new custom work and constantly changing customer demands and specifications.

Research revealed that there are no comprehensive surveys of the industry addressing formal product development practice. However, the author's experiences, the experiences of colleagues, and particularly unpublished reports from the professional placements of students from the B.Sc. degree in Furniture Technology, at Irish furniture companies show very little evidence of formal product development practice.

This situation might help explain why a number of small furniture companies have CNC machining centres. The desire to improve efficiency and the need to retain flexibility may have led small companies to choose CNC machines because the set-up times are generally shorter for most pieces and they don't have to maintain and store large numbers of cumbersome jigs. However, the cost justification for CNC machines often lies in being able to achieve repeatable quality in small-medium volumes of similar products, (Groover, 1980). In the author's experience in a five furniture and wood products companies the CNC equipment can spend less than four hours in production each day. Very few companies' produce the volumes of product usually associated with CNC and automated equipment. "*Traditionally furniture firms have been characterised by a high dependence on labour with little technological sophistication ... Technological developments have enabled furniture firms to introduce computers and equipment such as Computer Aided Manufacturing, that allow high quality products to be produced efficiently in small quantities to detailed design specifications*." (McFerran et al, 1999). The general move towards more technology and automation has slowly begun to reduce dependence on traditional skilled labour.

As revealed through the analysis of co-operative placement reports discussed in the next chapter, because many companies were making to customer specification, innovative design was not usually a major issue. However, most companies must deal with design for manufacture issues, and apparently have done so informally, through discussion and consultation with the clients. The rapid pace of technology integrating design and manufacturing has led many companies into CAD/CAM, but most seem to be lacking in the skills to take full advantage of it. The few remaining larger companies, which tend to be manufacturing product ranges, have a more structured approach to design, and some were found to have used furniture designers to assist them with new product ranges.

Since the author began investigating the use of DFM and process planning in the furniture and wood products industry in 2004, the industry has gone through dramatic changes. In the early part of the decade, a small number of larger companies were still manufacturing 'products' in reasonable volumes, and many smaller companies had a few product ranges they could manufacture in their factories/workshop alongside bespoke or custom projects. In the middle years of the decade, several larger manufacturing companies experimented with project based manufacturing and then either closed down or cut back their operation significantly. Many of the smaller manufacturers that had product ranges simply stopped making them in favour of more projects serving the lucrative construction sector.

These observations are anecdotal, but the author has consulted with colleagues and other experts including development advisors from enterprise Ireland and furniture industry consultants to confirm them. Thus, there was a period when it looked like the Irish furniture and wood products sector had almost abandoned product manufacture and moved exclusively into projects. However, with the collapse of the construction market, there has been a significant renewal of interest in product development. The evidence is again anecdotal but can be given some credibility by the huge increase in the number of small companies seeking assistance from GMIT Letterfrack with product development. Several of these companies have applied for and received funding from Enterprise Ireland to support their efforts. The nature of the type of assistance is also significant, with a major focus on the use of technology to design, develop and manufacture the products.

2.7 CNC Technology in the Furniture and Wood Products Industry

CNC technology came to the Irish furniture industry in the early 1980's and has steadily increased in application over the years. In recent years the industry appears to be catching up in terms of the changes in the systems and skills required to take full advantage of the technology. Conversations about the direction of the FWP industry often suggest that the sector has moved from trades-based production to a manufacturing systems and technology basis. Again, research into this phenomenon is beyond the scope of this thesis. However, the consequences of such a development have a major impact on process planning and particularly on who actually does it. Increasing numbers of GMIT graduates have been employed in recent years as CAD technicians, project engineers, engineering design and other related positions. They all involve the creation of 3-D CAD/CAM models of products and the production of workshop drawings, cutting lists, work orders, and work instructions, usually including CNC programs. The decision regarding the construction of the products is often in the hands of these engineers. In effect they, sometimes unwittingly, make many of the design for manufacture and process planning decisions, (ref P.Tobin. pers. conv. 2010).

Designing for CNC manufacture has emerged as a hot topic in the last decade. There have been many interesting projects in GMIT Letterfrack and other colleges internationally examining design for CNC manufacture. Some of the Letterfrack experiences with placement companies are examined in the next chapter.

Alan J Harp completed his MSc in Georgia Tech (2002) based on redesigning the 'Autumn Chair' to utilise more CNC manufacture rather than traditional processes, with some interesting results.

FIGURE 2.4 THE AUTUMN CHAIR (ALAN J. HARP, 2002)

- The original designers of the chair had attempted to design a chair for CNC manufacture, but Harp found that it is imperative to fully understand the technology before one can design for it. This was best illustrated by the original design specifying mortise and tenon joinery instead of dowel joinery. Harp concluded that a person that wishes to become proficient in designing products for CNC manufacture should expect to take at least one month of full time training of the hardware and software before beginning to design products for the technology.

- Harp ran into severe problems with the manufacture of the solid wood prototype. Due to the protracted nature of work in a research lab or workshop, some weeks elapsed between manufacturing processes and also between manufacture and assembly. While it could not be helped, it illustrates another process planning issue for solid wood products. Solid wood parts will move, change dimensionally, if you do not process them and assemble them in a short time frame. Thus, it would be very useful to consider this at the design stage of the product.

- The study was based on the manufacture of a single chair and showed significant time saving in processing time for some machining operations at the CNC compared to traditional processes. However, Harp points out that a 3-axis CNC machine cannot do everything. Preparation and finish operations etc are required regardless of how the parts are created.

- Time invested in CAD/CAM work can be significant and has to be included in the cost/benefit analysis. Also, as with many processes, trial runs, creation of jigs and 'tweaking' has to be done at the CNC also. Some parts at the CNC require multi step processes due to stock sizes. Some processes leave a 1mm or less thick skin of material around the part, so as to provide additional vacuum surface. This surface is then sanded off in a secondary operation.

- The CNC produces parts with great precision. Achieving this level of precision is a lot more time-intensive when making the parts in the traditional fashion.

- Not all parts are appropriate for complete manufacture on CNC. For example, some parts would make much better use of materials if they were processed differently. Other parts would perform better if made differently, e.g. steam bent or laminated curved parts would be stronger than machined curved parts. Small parts are more difficult to create because of the extra jigs and fixtures required to mount the parts to the table.

- A variety of CAD/CAM programs are needed for designers of products for CNC manufacture, as different systems have different specialisations. E.g. cabinet programs versus 3-D carving.

2.8 Review of Co-op placements reports

As previously mentioned, part of the research involved reviewing a selection of reports produced by GMIT Letterfrack students returning from their co-operative education placement. The placements involve in-company work experience. The students are required to undertake a specific project for the company during the placement period. Some of the projects undertaken in the past have included;

- performance improvement projects in production and assembly operations e.g. plant layout, process design, work study
- design and construction of jigs
- development of CAD drawings for product ranges,
- design and development of new products and product ranges
- development of computer based systems for scheduling, generating bills of materials and cutting lists
- product re-design for quality and cost improvements
- CNC program development

Most importantly for the purposes of this thesis, the students compile a report documenting their time at the company. As part of that report they are required to complete a company operations questionnaire. This gave valuable data on areas such as products, customers, R&D, Computer hardware and software, etc. But more importantly the reports included information about the production process, product design, production scheduling and control, process routings, data collection and more. A copy of the complete questionnaire can be seen in Appendix 1.

In all, 48 reports submitted within the period 2004-2009 years were reviewed. These companies were selected as being the most likely to have developed design and possibly process planning procedures. They were selected based on size, type of market and particularly on the advice of academic supervisors. In fact, the selection process was more of a process of elimination of very-small operations, and/or poorly managed businesses (again based on the advice of adacemic supervisors). From all the companies analysed, only four had a formal product design/development function.

- The first company identified are large producers of kitchen and bedroom doors. They have a very definite product development strategy. They employ a full time designer. However, the designers role extends to designing showroom spaces for their customers around the country. There would be insufficient work for a full time designer just for new products. The company launch between 1 and 2 new door styles per year. A new product launch is a well thought out and planned event.

- The next company identified is one of the largest furniture companies in Ireland. They produce furniture mostly for domestic application and in particular for the bedroom. They have a very formal design methodology with a R&D manager who becomes very involved in the design process. They have a vast product range and are constantly launching new products and designs. Their factory is highly automated and in turn is producing furniture in massive volumes on a daily basis.
- The third company manufactures mattresses. They have a very specific design and R&D function within the company. They are constantly developing new techniques to be applied to mattresses. Technically the author considered that this company falls outside the remit of this thesis as mattress production is more of an engineering exercise, (making and assembling springs, engineered foam structures, etc.) than being relevant to the furniture and wood products industry.
- The fourth company found to have a structured design and product development function operate in the office furniture market. They outsource their product development to a UK based design house. Most of their components are panel based. They strive to be at the forefront of their market and aim to offer customers innovative solutions to office fit-outs. The factory is a highly automated set-up which means there are not many processing alternatives.

The outcomes from this review are that most companies operating within the Irish furniture and wood products industry seem to have approached product development and product design as an unnecessary function in recent years. There was little evidence of any consideration to DFM or process planning in a formal and structured way. Those companies, mentioned above, are very large companies operating automated and high technology systems. However, as mentioned earlier, there is anecdotal evidence that companies had been completely preoccupied with the contract market for the construction industry and were not investing any time into product development.

2.9 Latest Research and Best Practice in Process Planning

The following briefly discuses some interesting topics and best practice directions in process planning.

2.9.1 Semantic knowledge modelling

Hapler (2007) defines a knowledge model as a way to abstract disparate data and information. "*Knowledge modelling is about describing what data means and where it fits. It allows us to understand and abstract knowledge. Consequently it helps us to understand how different pieces of information relate to each other*." Halper (2007) explains a semantic model is one kind of a knowledge model. "The semantic model consists of a network of concepts and the relationships between those concepts. Concepts are a particular idea or topic with which the user is concerned." The semantic knowledge model appears to be well suited to qualitative data about patterns and influences and can change as the knowledge changes.

Zhu et all (2010) apply the semantic modelling approach to process planning in assembly operations. They use this approach to generate process plans based on a virtual assembly tool. They claim that their approach improves assembly efficiency and makes the process intuitive and natural.

2.9.2 Octree Modelling

Medellin et al (2010) experimented with octree decomposition in 3-D CAD models to help generate process plans for robotic and manual assembly. They achieved some success but were limited by the approximation algorithm (using small cubes) in octree models. They claim that they are the first researchers to automatically generate process plans for manual assembly. Meagher (2007) defines Octree modelling as "*a new 3-D modelling technology developed to efficiently perform complex "spatial reasoning" operations with large datasets. It is currently used in medicine (craniofacial surgery, custom implant design, etc.) and industrial modelling using laser scanning.*" Kayacan and Celik (2003) developed a process planning database system based on the recognition of part features. They created an expert system linked to CAD solid models.

2.9.3 Stereolithography

A number of applications of process planning to stereolithograpy have emerged in recent years. Limaye and Rosen (2007) applied process planning to improve performance in high precision micro-fabrication technology. Petrzelka and Frank (2010) developed an approach to process planning for subtractive rapid prototyping. This type of applied process planning in a single hi-tech fabrication is a very forensic and detailed application. It would not be relevant to the higher level application of process planning required in the furniture industry.

2.9.4 Virtual Reality and Web Based Systems

Liu et al (2009) created a virtual reality application for assembly process planning that they claim improves the performance for complicated products. It allows the user to 'dry run' the process in virtual reality based on hierarchical assembly tasks. It also uses geometric constraints and a reasoning algorithm to help achieve the optimum process plan.

Web-based process planning systems are also being developed. For example, Jiang and Lu (2009) developed a web-based system for a specific automotive sub-assembly that could both generate new process plans and retrieve/modify similar plans.

2.9.5 Integration of Process Planning and Scheduling

There is a good body of research available on the integration of process planning and scheduling. Li et al (2010) reviewed the research in this area and presented conclusions on the application of the various approaches. In previous research with a different group Li et al (2009) experimented with particle swarm theory to help explore the solution space for processing planning/scheduling problems.

2.9.6 Fuzzy Logic

Aziz and Parthiban (1996) describe fuzzy logic as one of the most successful of today's technologies for developing sophisticated control systems. They explain that *"fuzzy logic addresses such applications perfectly as it resembles human decision making with an ability to generate precise solutions from certain or approximate information.* ".
They go on to describe fuzzy logic as an extension of conventional(Boolean) logic that has that handles partial values between "completely true" and "completely false". They also list the essential characteristics of fuzzy logic as-

- *"In fuzzy logic, exact reasoning is viewed as a limiting case of approximate reasoning.*
- *In fuzzy logic everything is a matter of degree.*
- *Any logical system can be fuzzified*
- *In fuzzy logic, knowledge is interpreted as a collection of elastic or, equivalently , fuzzy constraint on a collection of variables*
- *Inference is viewed as a process of propagation of elastic constraints.*"

Ngai et al (2008) combine fuzzy logic, particularly fuzzy set theory, with case-based reasoning, to provide a web-based decision support system for process planning. They focused on 'polishing' processes because of complexity, multiple criteria and attributes, and the vagueness of process parameters.

2.9.7 Neural Networks

Stergiou and Siganous (1996) describe how neural networks take a different approach to problem solving than that of conventional computers. "*Conventional computers use an algorithmic approach i.e. the computer follows a set of instructions in order to solve a problem. Unless the specific steps that the computer needs to follow are known the computer cannot solve the problem. That restricts the problem solving capability of conventional computers to problems that we already understand and know how to solve. But computers would be so much more useful if they could do things that we don't exactly know how to do.* "

They explain that neural networks process information in a similar way the human brain does. "*Neural networks learn by example. They cannot be programmed to perform a specific task. The examples must be selected carefully otherwise useful time is wasted or even worse the network might be functioning incorrectly. The disadvantage is that because the network finds out how to solve the problem by itself, its operation can be unpredictable.*" Whereas, conventional computers use a cognitive approach to problem solving that is totally predictable; if anything goes wrong is due to a software or hardware fault. They point out that neural networks and conventional algorithmic computers are not in competition but complement each other. There are tasks are more suited to an algorithmic approach like arithmetic operations and tasks that are more suited to neural networks. Some systems use a combination of the two approaches.

Neural networks have been used in process planning systems to solve unstructured problems. Butdee et al (2010) describe an example of such a system for die design and manufacture. Similar to furniture and wood product manufacture, they claim that the efficiency of die design and process planning are based on the knowledge and experience of die design and die manufacturer experts. They formulated this knowledge into a knowledge-based system which can be reused to support a new die design and process planning. Such knowledge can be extracted directly from die geometry which is composed of die features. Thus far, it is quite similar to the approach followed in this study to develop the process planning tool for wood products. However, Butdee et al went further and designed an artificial neural network to assist die design and process planning based on collaborative design methodology. With this neural network product data can be shared and distributed in die design team members via computer network technology. Again it is similar to our approach, and that of Humm et al (2001) in that die manufacturing cases in the case library would be retrieved for use in process planning. However, their approach to retrieval is based on searching and learning methods by the neural network for reusing or revising it to build a die design and process plan when a new case is similar to the previous die manufacturing cases.

2.10 Conclusions

The review of literature was continued over a number of years and revealed very little research in the areas of DFM or Process Planning in the furniture and wood products industry. It seems likely that very little effort has been made to take advantage of these techniques in the FWP industry, particularly in the type of small to medium sized enterprises that dominates the Irish manufacturing industry.

The review of the design to manufacture cycle, DFM and particularly process planning and CAPP suggests that process decisions or choices are made, consciously or unconsciously, at almost every step of the design to manufacture cycle. However, the final process plan might not be complete until just before manufacture, and it might be different each time depending on the current manufacturing conditions. The process decisions that are made earlier in the design cycle usually narrow the range of options for the final process plan. This view of process planning as a significant final step before manufacture has been challenged in recent years by the proliferation of

CAD/CAM systems in the furniture and wood products industry. This essentially shifts many construction decisions and consequently process decisions away from the experienced people in manufacturing and puts them in the hands of design engineers, who may or may not be experienced in manufacture. This raises questions about the timing of 'process planning'.

The potential to use the process planning techniques to assist with DFM earlier in the design cycle has not been formally explored or implemented in the furniture and wood products industry. Perhaps one of the reasons for this is that process planning, or even DFM, has not been implemented in the wood products industry and some work must be done on investigating this, and if necessary on developing process planning guidelines specifically for operations and processes in the industry.

While there are many interesting new directions in process planning research, the author feels that some of these may be too advanced or complex and of little interest to furniture and wood products manufacturers. The use of neural networks and fuzzy logic may hold some promise for the future. However, the most accessible options could be in the application of case-based expert systems, i.e. building up a knowledge base through the recording of information from previous cases and using an expert system to interrogate the knowledge base to provide information to process planners.

The author has decided to limit the scope of the investigation and not to consider scheduling and capacity issues at this stage. There are two reasons for this; firstly, the research is focused on using process planning techniques at several stages of the design to manufacture cycle where scheduling would not be an issue, as well as at the point of manufacture; secondly, introducing scheduling/capacity criteria could overcomplicate the analysis at this stage and may hamper progress.

3. Design for Manufacture and Processing Planning in the Irish Furniture Industry

3.1 Introduction

The purpose of this chapter is to confirm formal and informal practices of DFM and process planning in the furniture and wood products industry. Questions raised will be addressed in live process planning workshops trials. Following the literature review, particularly the review of the placement companies, further exploration of a number of case studies will highlight DFM issues involving CNC technology. Chapter 4 will cover the process trials.

Based on the literature review and conclusions there are three steps at this stage of the research.

(a) To search for industry specific evidence of DFM and process planning in practice.

(b) To conduct company interviews to gather information relating to process specific changes/modifications

(b) To conduct live process planning trials to aid in determining the approaches currently being adopted.

(c) To analyse the outcomes of the above and develop process planning guidelines and a process planning methodology.

3.2 Primary Research Methodology

The flow of primary research is depicted in figure 3.1. It identifies the broad research actions taken. Some of these require further explanation which follows the diagram.

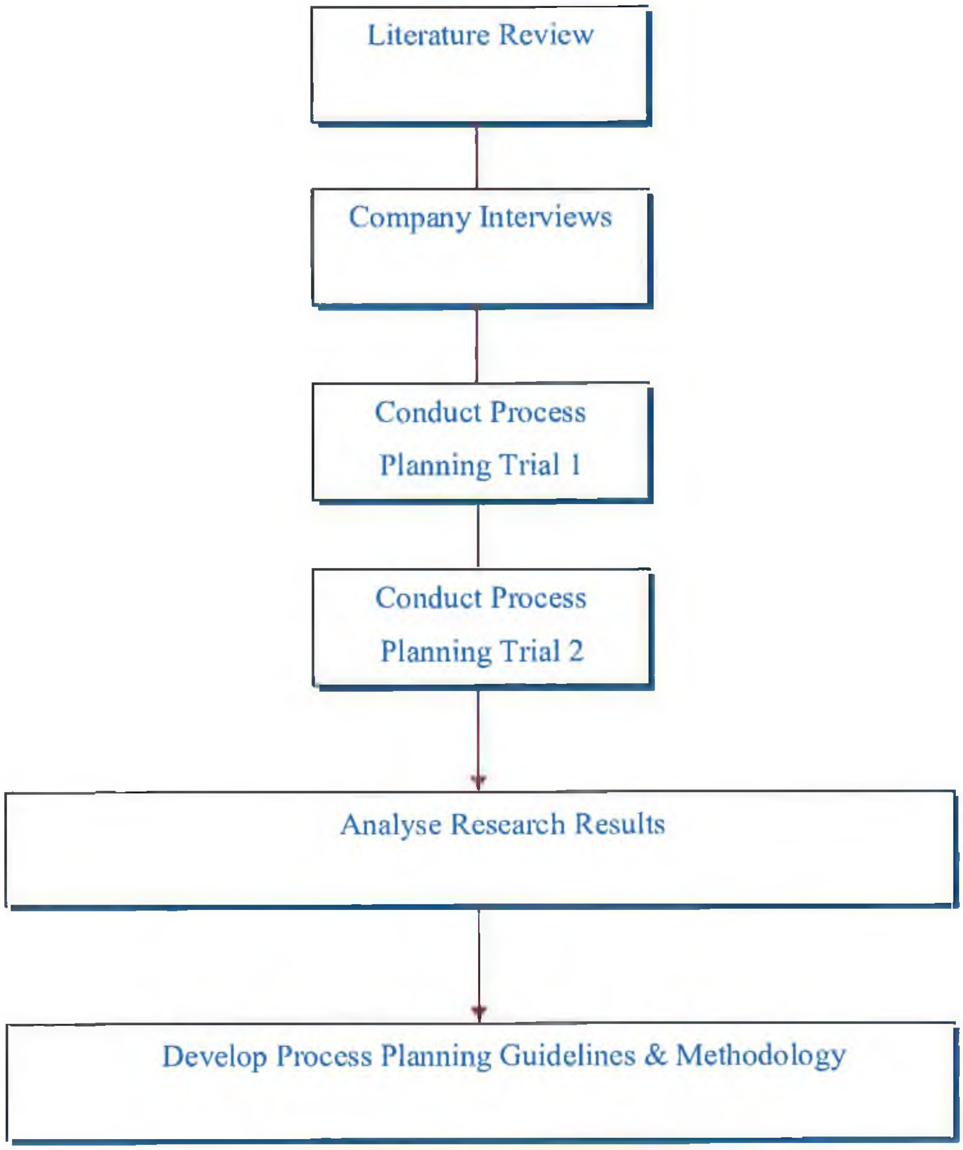

FIGURE 3.1 SEQUENCE OF PRIMARY RESEARCH ACTIVITIES

Case Studies/Interviews

Six companies A small number of DFM issues emerged from the company reports particularly related to CNC technology. It is likely that a rigid survey would not have uncovered these cases. The cases were explored further and the key points are highlighted.

Process Planning Trials

Eight highly qualified and experienced technicians and lecturers at GMIT were given two sets of product drawings, in the same way as the literature suggests many process planners would receive data. Each person developed a set of process plans, and the author manufactured the products according to the plans and measured the results.

Analysis of data

The data from the process plans were analysed in the context of the results of the literature review, industry review, and company interviews to aid a sample set of guidelines for specific processes and some conclusions regarding an overall process planning methodology.

Development of Process Planning Guidelines and Methodology

This involved the development of a structure for the use of the guidelines within an overall design-to-manufacture methodology.

3.3 Company Interviews

Out of the 48 reports reviewed, six companies (five in Ireland and one in the US) involved in the furniture and wood products industry were chosen to examine further as they were doing interesting things related to DFM and process planning, albeit informally. They also had technology based production equipment or were involved in its use. The companies chosen varied in their size and the type of product they generate. For the purposes of confidentiality, alias names are used in this thesis.

The companies are all familiar to GMIT Letterfrack through the co-operative education placements. This made approaching them for information a less daunting task. The information from each company will be presented, as gathered, in the following format:

- Company description
- Interviewee
- Explanation of processes
- Problems encountered and challenges
- Lessons learned

3.3.1 A-Wood

Company description

A-wood is an American based company. They are producers of high end architectural joinery. The company have 90 full time employees. A-Wood gives an example of how applying DFM principles mixed with CAD/CAM and CNC technologies resulted in the company winning a massive contract by being intelligent in their approach to interpreting architects drawings.

Interviewee(s)

The information in this section was gathered from two students working on placement with the company as well as their supervising lecturer. The author did not visit the company due to travel constraints.

Explanation of processes

They have a full range of processing options varying from traditional equipment to high technology CNC machining centres. The company in question does not design or develop any products themselves. All work is received in the form of architectural drawings. Every job is analysed and engineered to suit the facility.

Problems encountered and challenges

The company were asked to tender for a very complicated fit-out of a new modern theatre. The theatre is domed in shape. The architects specified that the complete interior was to be fitted out in timber. The company owner commented that it was similar to trying to apply timber panelling to the inside of a large egg. To achieve this, compound curving timber panels, were required.

All the other companies who tendered for the contract were proposing to use solid timber because of the complex geometry. A-wood was awarded the contract for being 20% cheaper than the next nearest tender. They achieved this in a very clever way. Instead of using expensive solid wood they used veneered panels. This still gave the 'look' the architects required but reduced the raw materials and processing costs massively. How were they the only company able to achieve this? They proposed to precision engineer each of the panels using CAD systems with flattening technology and 5-axis CNC hardware. Because each of the panels was a compound curve, creating the manufacturing instructions became very complex. Every panel was different to all others. The flattening technology software takes the compound curved component and approximates its shape when flat. This gives a flat panel with curving edges which is easily made on a 5-axis CNC. The panels are thin enough to bend into the required shape when positioned.

Lessons learned

This is a fine example of a company who were challenged with a manufacturing problem, and interpreted a manufacturing problem in a different way to all others to win the contract. They engineered the products to create the same end result even though they were constructed in a different way. In essence, a real application of DFM principles being integrated with new technologies. They could envision a different way of doing it by considering alternative processing options. All the other companies were biased and had a preference towards making it in solid wood through a lack of knowledge of available processes.

3.3.2 B-Wood

Company description

B-Wood manufacture bespoke furniture, architectural joinery as well as some general woodworking. The company has 12 full time employees.

Interviewee(s)

The information in this section was gathered from a visit to the company where the manager/owner and production manager gave the author a tour of the manufacturing facility and then subsequently answered questions in the production office.

Explanation of processes

The company utilise a full range of traditional woodworking machinery. Approximately 3 years ago a CNC workstation was purchased. A number of products are manufactured by request namely, tables, chairs, display cabinets etc. but the design of these products have not changed in years. Most of the companies work for the last number of years has come from architects or engineers. They are quite organised in how information is sent from the office to the workshop floor. On receiving the drawings, the production manager re-draws them in a format that can be understood by personnel on the workshop floor. This highlights to him any constructional issues that may arise. Full specification working drawings are sent to the workshop floor ready for processing.

Problems encountered and challenges

It was obvious from discussion that there were many difficulties in transferring their approach from a traditionally focused one to a more technological concentrated method. They were not familiar with formal DFM or process planning techniques. When it was explained to them, they acknowledged they were doing both (informally) on a continuous basis.

They encountered problems transferring products from traditional woodworking methods to an approach focused towards maximising the benefits of their new CNC. It required them to re-think how they have designed and assembled certain products which they have been making for years. This was based on the assumption that the CNC would be more productive. This demonstrates how process planning decisions can be affected from the design stage. They were purposefully restructuring their products because they *wanted* to make them on the CNC. It is interesting to note the comment that the only reason for doing this was to utilise the CNC because they now had it. The decision was not based on any logical process planning decision procedure or structured analysis.

Lessons learned

They are faced with the challenge now of finding a fit between forcing products onto the CNC and using, perhaps more efficiently, the traditional processes that sometimes work better anyway. It is obvious this company did not give enough thought to how they were going to migrate their products to get the best benefits from the CNC. There was not enough planning in advance of their purchase. Three years later they are still going through an extended learning curve.

3.3.3 C-Wood

Company description

C-Wood is a small kitchen making business. They only use panel sheet material and no solid wood at all. The products are sold to the mid to lower end of the price market. The company have four employees.

Interviewee(s)

The information in this section was gathered from a visit to the company. The production manager gave the author a tour of the manufacturing facility and answered questions afterwards.

Explanation of processes

Their processes are very traditional, involving old machinery and methods of working. Based on the advice of an industry consultant, the company decided to embrace CNC technology and purchased a beamsaw with panel optimisation software and a CNC workstation with routing, drilling and grooving capabilities (ideal for panel production). This involved changing the construction methods employed by the company for years. Cabinets were screwed together which gave rise to some quality issues. There was also a reasonably high level of re-work and scrap. Now the cabinets are assembled with KD fittings.

Two years after implementation and the changes have surpassed all their expectations. Productivity has increased. Quality has soared. Re-work is almost redundant and scrap and waste material has diminished. Most importantly profits have increased four-fold within the two years. This is even in a diminishing market. Their sales dropped, but they believe not as much as their competitors. The company attributes this to it having a competitive advantage.

Problems encountered and challenges

Overall they were challenged with many problems with the way they were operating. By confronting the situation and making the changes, they have now received the rewards that new technology can embrace.

Lessons learned

They knew exactly what they wanted and expected from switching to technology. Their traditional method of manufacture did not allow for changing their processes and so purchased equipment to allow them choose a different process plan. They introduced the new technology and altered their designs to suit in a planned and structured manner. They have reaped the benefits as a result.

3.3.4 D-Wood

Company description

D-wood is a very small company that manufactures custom wooden surfboards. They don't use any working drawings or technical specifications. They have measurements they work to depending on the style of board but the rest is down to the experience of the trained eye to create the shape of each board. They have two people working in the company, one of whom is a graduate of GMIT Letterfrack. For his final year thesis he wanted to explore alternative approaches to making surfboards as it was completely manual and very labour intensive.

Interviewee(s)

The information in this section was gathered from a visit to the company's small premises and from a discussion with the owner/manager.

Explanation of processes

While attending GMIT Letterfrack as a student he was very much craft based in his approach to woodworking in general. He had a self confessed phobia of using the CNC.

He knew what the machine could do but never thought it could be used for producing something as organic as a wooden surfboard. On realising that it may be possible he describes the moment as that resembling an 'epiphany'.

The process involved exploring how the board was constructed. Weight is a very important factor and the preference is for a very light surfboard when finished. To achieve this, the assembly of the main surfboard blank, was redesigned into sections (ribs) and then a drawing created and ultimately a CNC program for each section. This was quite complicated as the components were square and parallel in plan but curved in section. Each rib was different in profile meaning that no two components were the same. A series of 'pockets' were routed out of each rib thus removing a large percentage of the material and as a result the weight. Location holes were drilled into each rib for dowels. This removed any guess work from the gluing up process and also removed the natural tendency of the ribs to 'slip' out of position when the clamping pressure is applied. The final shaping of the surfboard blank was still manual. This is because the CNC machine used, was not a 5-axis machine with 3D carving ability. If a 5-axis machine was available, the assembled blank could have been mounted onto the machine and the final shaping would have been possible.

Problems encountered and challenges

Currently they are making the surfboards manually as they do not want to invest in CNC technology. The scale of production does not warrant it. The main problem encountered was, in the students own words, "making the psychological change to thinking for CNC" as opposed to his trusted traditional tactics.

Lessons learned

With a lot of uncertainties they were brought to CNC technology and their eyes were opened. By exposure to CNC they were able to redesign the product to take advantage of their new understanding of the processes. They now have an opportunity to outsource the ribs for the blanks which would lower production time and remove the manual dependency of their current approach.

3.3.5 E-Wood

Company description

E-Wood is a large scale kitchen and bedroom door manufacturer and supply their products to the Irish trade market. The company currently has 31 full time employees. The company is very structured in how work orders are sent to production. An order is sent out with all component sizes, and the style of door. This indicates material type, finish required, and the type of tooling required for processing. This information is easily interpreted by workshop personnel.

Interviewee(s)

The author has previously worked for this company in the past. The company has grown considerably since then. A tour of the factory was followed by a discussion with the Owner.

Explanation of processes

They initially started out making kitchen doors with traditional processing equipment only. This was in the late 70's and there were no other alternatives available at the time. The company owner takes pride in the fact that they were one of first companies to import a CNC router into Ireland in the early 80's.

He also recounts the story of being challenged by his employees. They claimed that they could make the curved door components faster than the new CNC using the techniques they had previously been using. The owner accepted the challenge. They both had to produce a large batch of centre door panels with a curved arch on the top. The CNC was set-up and processing panels relatively fast and had about 5 panels produced before the equivalent process was set-up on the spindle moulder. However, as the spindle moulder had a larger and more powerful cutter, and allowed for faster feed speeds even though manually fed, it soon caught up and passed with ease, the pace of the new machine. This example does tend to substantiate how CNC machining centres are very flexible for fast change over between products and for small batch runs, but are not suited to high volume production.

Problems encountered and challenges

Currently the company outsources a large percentage of its products. They do however, still have full scale production equipment for making off-standard units as they are ordered. Problems they have encountered are that their expensive equipment is no longer being utilised to its full capacity as most of their products are being imported from cheaper economies. Their justification for retaining such capital intensive machinery lies in the flexibility that the CNC equipment offers for rapid set-up for small batch runs. They acknowledge that much more economical traditional machinery would suffice for producing the off-standards, but they believe the labour cost mixed with the quantity of jigs required for various door designs and sizes, and the longer lead time for the customer would be more costly in the long run. They believe their main challenge is finding a fit to exploit the available capacity on the CNC machinery.

Lessons learned

This case demonstrates that while CNC's are powerful and flexible machines, they certainly are not the answer to all manufacturing problems. This case has also identified that you cannot bring a CNC into your company and push the products through it. Traditional machines most certainly still have their place.

3.3.6 F-Wood

Company description

F-Wood is a high end kitchen and bedroom manufacturing company. The average price for their kitchens is approximately €50,000. They have 15 people employed full-time. During the peak of economic activity they had around 2 years worth of work on the books. Now it is literally month by month as the work comes in. F-wood is very structured in the approach they use when releasing work orders. Every job is drawn in full detail. From this a lot of production information is extracted. It gives individual panel sizes for the doors, and also the carcasses. Usually a different operator prepares the material for the carcasses and the doors. The drawings also give details of other ancillary components required for the job such as mouldings, worktops, handles, lighting, drawers hardware, and so on. A final year student at GMIT Letterfrack had spent his co-operative placement with the company.

Interviewee(s)

The information in this section was gathered by visiting the company. A tour of the facility was followed by a discussion with the production manager.

Explanation of processes

The company invested circa €500,000 on a new 5-axis CNC machine and associated tooling. In line with current trends, most of the kitchens being produced are painted. The doors are simply machined from MDF sheets and then painted. They employ a technique known as nesting. This is where the sizes of all components are input into software and it optimises the best layout to machine them from a large sheet. While on placement at the company, the student took an interest in the whole area of nesting and decided to base his final year project on the topic. They wanted to analyse the efficiencies of nesting versus the more conventional route of cutting the panels slightly oversize on a beamsaw and then using a CNC (without nesting ability) to profile the edges and apply a pattern into the centre of the door. This was interesting because the beamsaw and CNC are still considered new technology. Nesting is a newer development yet again. This project in essence was comparing new technology to newer technology.

The trials took a set of doors for one kitchen and manufactured them using nesting firstly, and then the same set of doors using the beamsaw and the CNC (without nesting ability). The nesting trials were conducted at F-Wood. The doors were timed as they were produced on the nesting CNC. The beamsaw and CNC trials were conducted in the machine hall in GMIT Letterfrack. Both scenarios were recorded using time and motion study techniques. For the nest based trials the doors were produced in 1 hour and 11mins. The route of the beamsaw and CNC router finished the task in 1 hour and

43mins. Therefore, the nest based process was substantially more time efficient than using the beamsaw followed by a CNC.

Problems encountered and challenges

The company are now faced with having a costly 5-axis CNC machine being underutilised due to low order volume.

Lessons learned

Even though the woodworking industry is around a long time, anybody in the industry has to keep an open mind because new ideas and new ways of doing things are continuously being developed. This is especially true for the technology sector of the industry.

3.4 Conclusion

What lessons have been learned from the case studies?

- By having an innovative approach and an open mind, combined with DFM principles, companies can use new technology to produce components in ways that may not otherwise have been considered.
- A considerable investment in time is required, by personnel, to understand the processing possibilities and capabilities of CNC machines. Instead of forcing products to the machine, a structured approach to re-design is required. This may result in better utilisation of both CNC's and existing traditional equipment.
- There is a suggestion that while CNC equipment is flexible for small batch runs and achieves fast set-up times, traditional machines are likely to be better for large volumes.
- Process planners need to know the capabilities of all the technologies. A broad knowledge of a wide range of processes is necessary.

There is an indication that the core material being processed (solid wood, MDF, Chipboard, etc.) has an influence on the success of the integration of CNC technology. B-Wood largely uses solid timber for their work. They are still having problems adapting. D-Wood use mainly sheet material and are enjoying the benefits of the technology. It is possible that from a DFM point of view, it may be much more difficult for solid wood companies to introduce CNC technology than it is for panel based companies.

It is difficult for any process planner to have a wide knowledge of all the machines and an in-depth knowledge of what each can do. It is possible that people do not know enough about CNC's, beyond their basic functions, and their potential to carry out advanced processes on them. It is likely users do not have enough experience and also, the technology is changing all the time.

The case studies focused on CNC's. The studies suggest the need for support to assist the process planner.

4. Process Planning Trials

4.1 Introduction

The main element of the primary research was the development of process plans by a number of highly qualified and experienced people and the implementation and measurement of these process plans. Earlier in this report it has been indicated that process planning in the furniture and wood products industry is being carried out informally, by designers, technical office staff, workshop technicians, etc. To ascertain the effectiveness of this approach, process planning trials were conducted to gather realistic data from experienced users and to evaluate implications this may have.

Based on experience, and knowledge gathered from the company interviews, the transition of information from the drawing to production stage can take many different forms such as:

- CAD/CAM files
- Working drawings showing full constructional details and sections
- Drawings with no constructional details
- Photographs
- Concept sketches
- A rough outline sketch on a waste piece of wood (as seen by the author in a number of companies)

The approach varied from company to company and seemed largely dependent on the size and structure of the company. The understanding of this author was that the process planner would analyse the drawings of the product, in whatever form they are presented, and based on their best reasoning, come up with a processing decision for the components out of all the options available to them. To illustrate how such options are possible, the machining alternatives for producing a straight groove on a section of timber using the machinery in the workshop at GMIT Letterfrack are:

- Spindle Moulder
- Overhead Router
- Hand Router
- Table Router
- Weeke CNC Machine
- Rye CNC Machine
- Panel Saw

All of the above processes will give the desired end result, i.e. a straight groove. However, when all relevant factors are taken into account, one of these processing options is likely to produce greater efficiencies for set-up and processing of the groove.

As will become evident from the process trials, different people have preferences for using different processes. These preferences may have developed from the level of training they received on a particular machine, their experience on that machine, their perceived ability of a machine to do the job best or just personal preference. The vast array of machines available to the furniture industry includes both specialised and/or multi-purpose. For example a stair trencher will do just that, trench out housings for the risers and threads. A spindle moulder however can profile, groove, rebate, house, tenon and more. Based on extensive visits to many furniture manufacturing companies, both nationally and internationally, the majority of wood product workshops have many multi-purpose machines. This in turn allows for a number of machines which could be chosen to produce the same end result, be it an edge detail, groove, curve, etc. The machine workshop in GMIT Letterfrack has many such machines and therefore makes it a suitable to conduct the process trials as it replicates an industrial set-up.

4.2 Process Trials Methodology

For these trials the author designed two wood products that were intended to be process neutral, i.e. they were not designed to be processed on any specific machine. This approach was chosen as opposed to giving a design brief because the results could have been too varied and would not have given appropriate results for this project.

Eight technical staff at GMIT Letterfrack were asked to process plan the manufacture of both of the wood products. The 8 technical staff are all very experienced in furniture manufacturing. Some however are not trained or have little familiarity with the CNC machines. Therefore they would rely on a more traditional manufacturing approach.

The first wood product used for the trials is a jewellery box as shown in figures 4.1 and 4.2. This project was designed to include housing, rebating as well as stopped and through grooving operations which can be carried out on a number of different machines. Also, the Jewellery box is made from solid timber. This machines differently to man-made board such as Medium Density Fibreboard (MDF), chipboard, plywood, etc. and therefore may influence a person's decision to use a particular process.

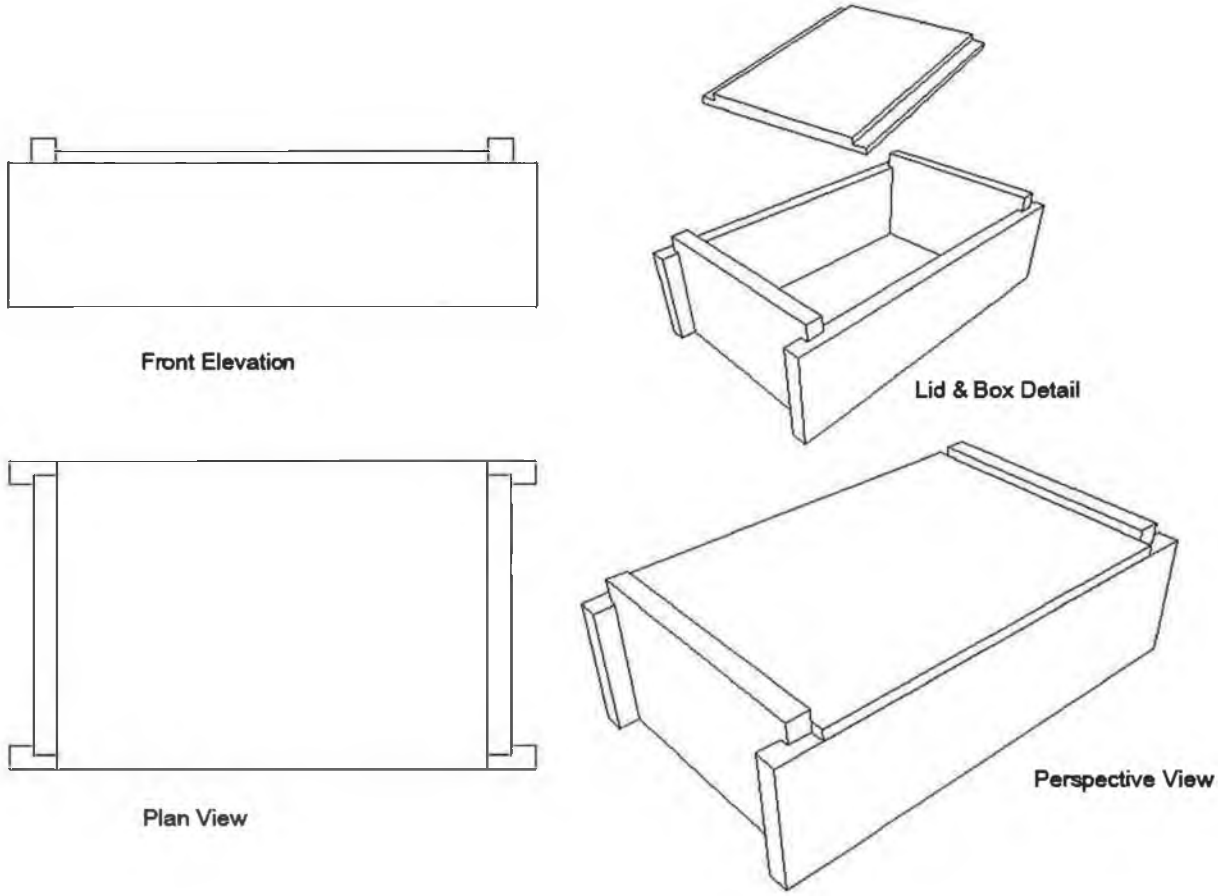

FIGURE 4.1 JEWELLERY BOX DRAWINGS

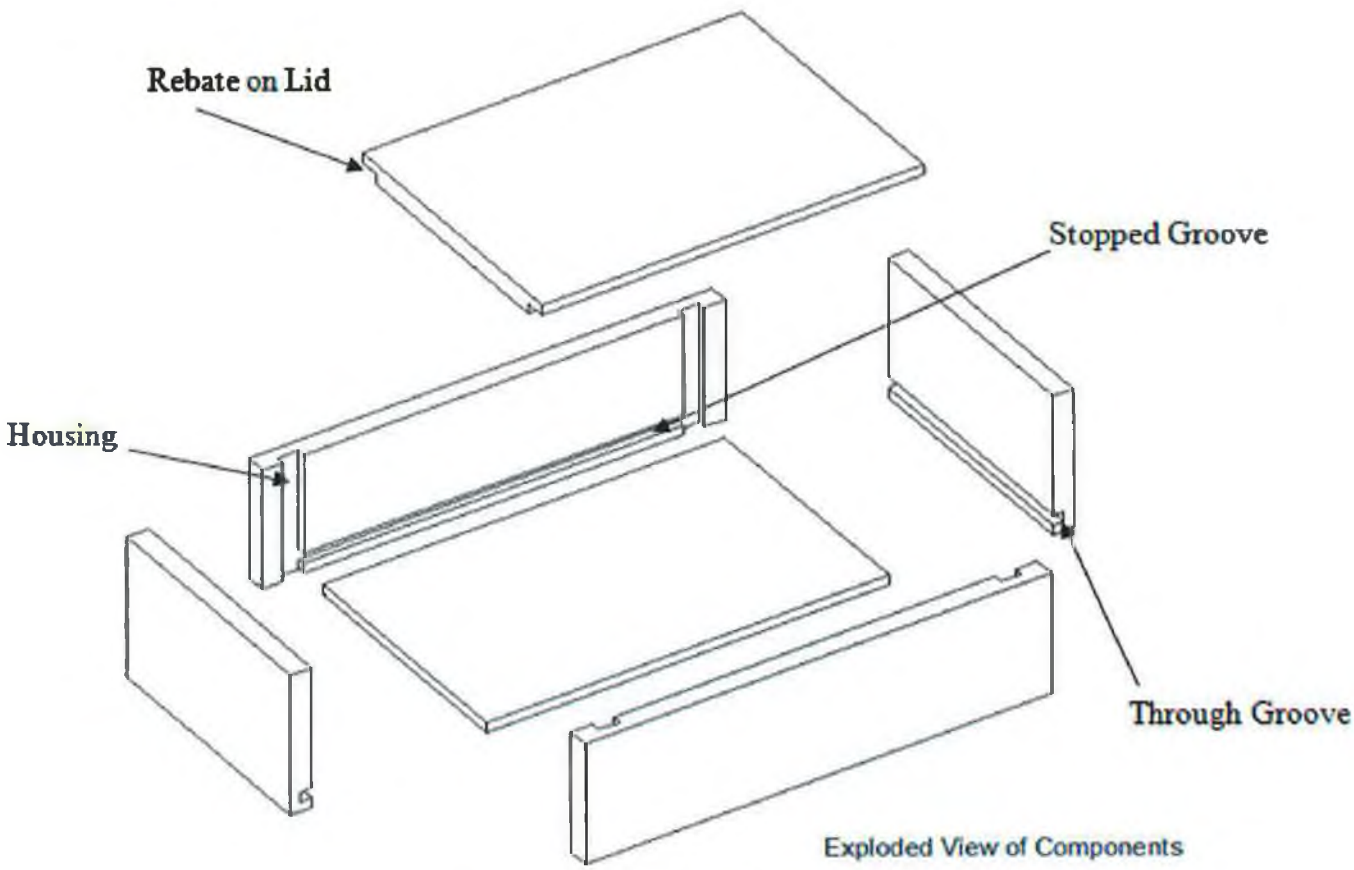

FIGURE 4.2 JEWELLERY BOX COMPONENTS

FIGURE 4.3 SOME OF THE COMPLETED JEWELLERY BOXES AFTER THE PROCESS TRIALS

FIGURE 4.5 SHOWING THREADED INSERTS ON BOTH CURVED SHELVES

The curved shelf is produced from MDF and assembled with knock-down (KD) fittings. Figure 4.5 above shows threaded inserts fixed into horizontally bored holes. Figure 4.6 below shows one assembled shelf. A corresponding decorative bolt is tightened with an allen key into the threaded inserts to complete the assembly.

FIGURE 4.6 CURVED SHELF UNIT COMPONENTS

For both process planning trials, the component blanks were pre-prepared. In the case of the components for the jewellery box the timber was planned all round and cut to length, ready for the grooving, housing and rebating operations.

The difference between a housing and a groove is that a housing is a channel cut across the grain and a groove is a channel cut in the direction of the grain.

For the curved shelf unit the components were cut into square sections ready for their next process. This preparation time was not included in the final times for the trials as the process planning decisions were made from this point forward.

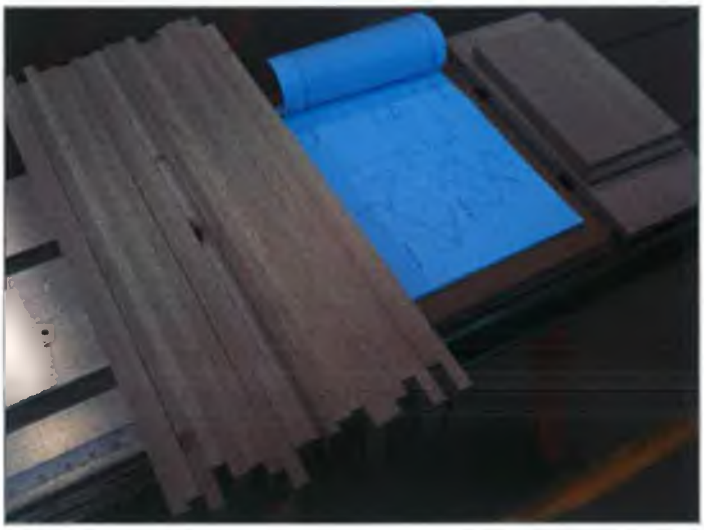

FIGURE 4.7 JEWELLERY BOX COMPONENTS

The pieces shown in figure 4.7 above have been prepared on the surfacing and thicknessing planners. They are shown above on the table saw ready for cutting to exact length.

All of the eight process planners were asked by the author, to describe in detail what equipment or methods they would use to produce the components for one jewellery box, i.e. devise a process plan. They were then asked to repeat the procedure for a batch of ten jewellery boxes. The reason for this is that different equipment or methods are more suitable for larger volumes. This was identified in the case studies earlier. By using the same product for a small and large batch it should help in building a picture of the varying approaches to process planning by different people. In addition, if a certain machine has a long set-up time this would make it uneconomical for producing one or two components. If the set-up time is divided among a larger amount of units then the set-up time per part is much less and may be justified.

The process or processes chosen for each component by the process planners were recorded. The components were then manufactured according to each process plan using the equipment in the machine hall in GMIT Letterfrack. This work was carried out by the author. The author feels that he is suitably qualified for this task as he has over 16 years experience as a furniture maker, working at the highest level of the industry. He has won a prestigious 'Guild Mark' from the Worshipful Company of Designer Craftsmen in the UK for producing work of exceptional quality. Furniture produced by the author has been displayed in galleries in Ireland and the UK. The author has 11 years of lecturing experience teaching both the theory and practical instruction of the machinery used in the process planning trials. He has also worked as a consultant with furniture and wood product companies in Ireland, the UK and the US. This work included implementing training systems for employees on woodworking machinery, finishing systems and techniques, machinery and equipment plant layout, and more.

For the purposes of this thesis the names of the process planners will remain anonymous. The process route chosen by each process planner will be called process plan 1 for the first participant, process plan 2 for the second, and so on. For the eight process plans, there were many different process routes chosen for the same component. Some planners choose identical routes to each other and some choose very different routes.

4.3 Process Planning Trials for 1 Jewellery box

To gather the necessary process planning information, the manufacture of the jewellery box was divided into components and then processing decisions to be carried out to each component. These are as follows:

TABLE 4.1 PROCESSING DECISIONS REQUIRED – JEWELLERY BOX

Component	Processing Decisions Required
Long Sides	Housing
	Stopped Groove
Short Ends	Through Groove
Lid	Rebate

Please refer to figure 4.2 earlier for identification of the processes on each component.

Following are the process plans produced by the eight technical staff for the manufacture of one jewellery box and the recorded times for set-up and producing each component according to those plans. Photographs are included where appropriate, of the components being produced during the trials.

TABLE 4.2 ONE JEWELLERY BOX PROCESS PLAN 1

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Long Sides	Housing	Prepare the components to the width of 2 so they would fit onto the Weeke CNC. Machine & cut into individual components simultaneously	00:06:23	00:01:40	00:08:03
	Stopped Groove	N/A - Cut during above process	00:00:00	00:00:00	00:00:00
Short Ends	Through Groove	Both cut together on the Weeke CNC	00:02:52	00:01:40	00:04:32
Lid	Rebate	rebate removed on the Weeke CNC	00:01:26	00:01:36	00:03:02

Total time for all components		00:15:37
No. of Machines/tools used	1	

FIGURE 4.8 LONG SIDES ON THE WEEKE CNC

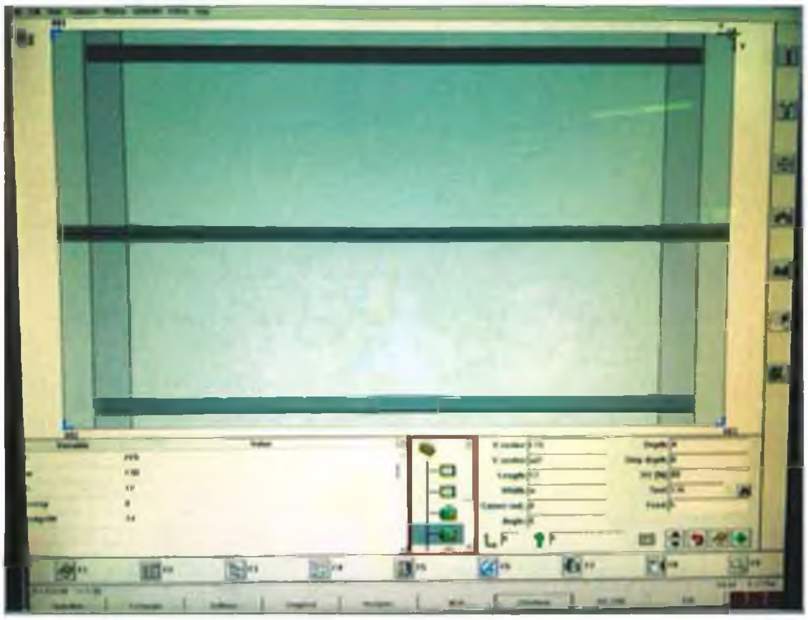

FIGURE 4.9 PROGRAM USED FOR LONG SIDES ON THE WEEKE CNC

Figure 4.8 on the previous page shows the completed long sides on Weeke CNC. Figure 4.9 above shows a graphic of the program used to create the parts. The software used is called WoodWop and it was developed for the Weeke by the Homag Group. The Week CNC machine used for these process trials is shown in figure 4.10 below.

FIGURE 4.10 WEEKE CNC MACHINING CENTRE

TABLE 4.3 ONE JEWELLERY BOX PROCESS PLAN 2

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Long Sides	Housing	Rye CNC - including making a jig for holding components	00:22:06	00:01:56	00:24:02
	Stopped Groove	N/A - Cut during above process	00:00:00	00:00:00	00:00:00
Short Ends	Through Groove	Spindle Moulder	00:06:48	00:00:22	00:07:10
Lid	Rebate	Spindle Moulder	00:07:35	00:00:39	00:08:14

Total time for all components	00:39:26
No. of Machines/tools used	2

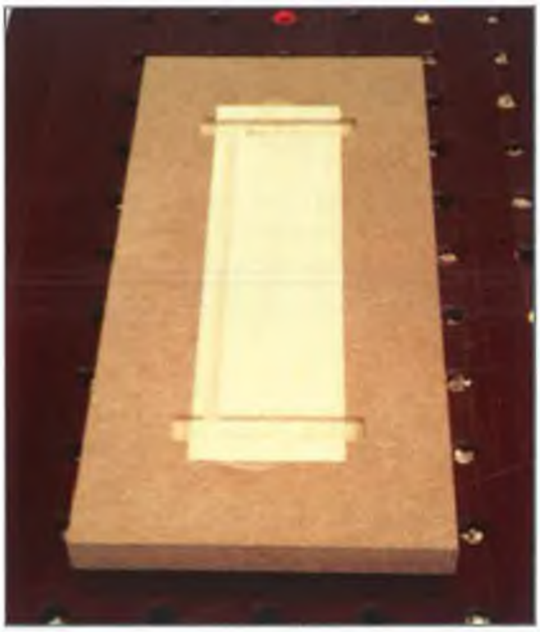

FIGURE 4.11 LONG SIDE ON THE RYE CNC

Shown in figure 4.11 is one long side, held in a specially constructed jig on the Rye CNC. The stopped groove and housings have been machined. The time taken to produce the jig is included in the set-up time.

On analysing the following process plans it became evident that some of the planners had chosen identical routes. In this instance process planers 3, 6, 7 and 8 returned matching routes.

TABLE 4.4 ONE JEWELLERY BOX PROCESS PLAN 3, 6, 7 & 8

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Long Sides	Housing	Table router	00:08:25	00:01:06	00:09:31
	Stopped Groove	Table router	00:07:50	00:00:49	00:08:39
Short Ends	Through Groove	Table router (already set-up)	00:00:00	00:00:25	00:00:25
Lid	Rebate	Table router	00:04:54	00:00:33	00:05:27

Total time for all components		00:24:02
No. of Machines/tools used	1	

FIGURE 4.12 LONG SIDE HOUSING ON THE TABLE ROUTER

FIGURE 4.13 LONG SIDE STOPPED GROOVE ON THE TABLE ROUTER

Figure 4.12 shows the housing being machined on the table router. The component is supported by a push board. This keeps the piece square to the fence and also prevents breakout on the back edge of the component when the cutter comes through. Figure 4.13 above shows the stopped groove being machined on the table router. Two end stops are attached to the fence. They dictate the length of the stopped groove and ensure it stops without running through the housings. Figure 4.14 below shows one of the router tables used for the process trials.

FIGURE 4.14 THE TABLE ROUTER

TABLE 4.5 ONE JEWELLERY BOX PROCESS PLAN 4

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Long Sides	Housing	Overhead router	00:09:30	00:01:11	00:10:41
	Stopped Groove	Overhead router	00:02:44	00:01:15	00:03:59
Short Ends	Through Groove	Overhead router	00:00:00	00:00:58	00:00:58
Lid	Rebate	Spindle Moulder	00:07:35	00:00:39	00:08:14

Total time for all components	00:23:52
No. of Machines/tools used	2

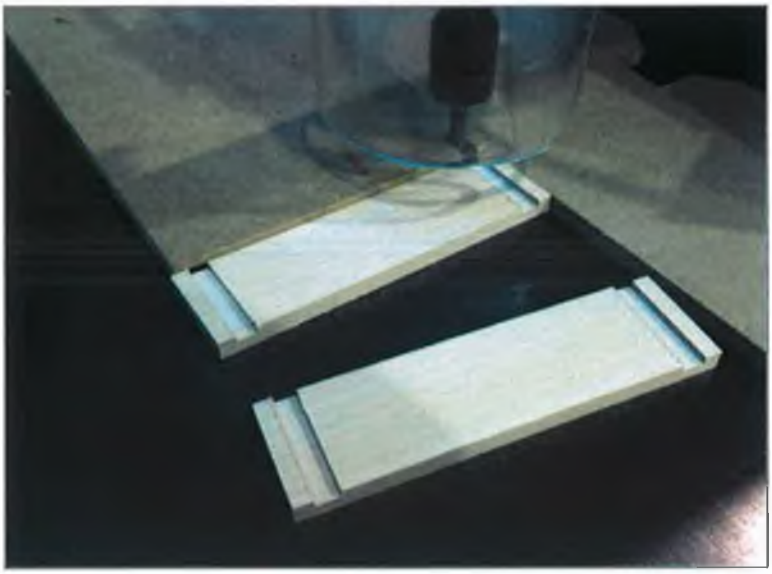

FIGURE 4.15 LONG SIDE HOUSING ON THE OVERHEAD ROUTER

Figure 4.15 shows the housing being machined on the overhead router. For this process the component is also supported by a push board to keep the piece square and prevent breakout.

FIGURE 4.16 THE OVERHEAD ROUTER

Figure 4.16 above shows the overhead router used in the process planning trials. The main difference between this machine and the table router is that the cutter removes material from the top of the component with the overhead router, and the bottom of the component with the table router.

TABLE 4.6 ONE JEWELLERY BOX PROCESS PLAN 5

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Long Sides	Housing	Table saw to just above full depth and finish with chisel	00:07:51	00:06:48	00:14:39
	Stopped Groove	Overhead router	00:02:44	00:01:15	00:03:59
Short Ends	Through Groove	Spindle Moulder	00:06:48	00:00:22	00:07:10
Lid	Rebate	Spindle Moulder	00:07:35	00:00:39	00:08:14

Total time for all components		00:34:02
No. of Machines/tools used	3	

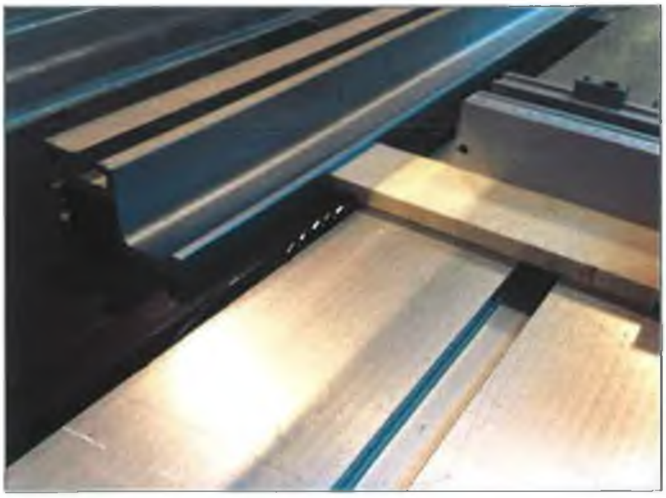

FIGURE 4.17 LONG SIDE HOUSING ON THE TABLE

Figure 4.17 shows the housing being cut from the long side on the table saw. For analysis and comparisons of the above results please refer to section 4.6

4.4 Process Planning Trials for 10 Jewellery Boxes

Upon completion of the process plans for one jewellery box, the eight process planners repeated the exercise with a batch quantity of ten jewellery boxes. Some of the planners chose the same processes for ten boxes as for one box, others changed to processes they had originally avoided as they commented the processes had a perceived longer set-up time, but now felt would be worth using because of the larger volume of components. The following are the process plans produced by the process planners for the manufacture of a batch of ten jewellery boxes and the recorded times for set-up and producing all components. It is worth noting that eight different sets of process plans were produced by the eight process planners for a batch size of ten, as opposed to four planners choosing an identical route for the manufacture of one box.

TABLE 4.7 TEN JEWELLERY BOXES PROCESS PLAN 1

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Long Sides	Housing	Double up the components so they would fit onto the Weeke CNC. Machine & cut into individual components simultaneously	00:06:23	00:16:40	00:23:03
	Stopped Groove	N/A - Cut during above process	00:00:00	00:00:00	00:00:00
Short Ends	Through Groove	Both cut together on the Weeke CNC	00:02:52	00:16:40	00:19:32
Lid	Rebate	rebate removed on the Weeke CNC	00:07:35	00:06:30	00:14:05

Total time for all components	00:56:40
No. of Machines/tools used	1

TABLE 4.8 TEN JEWELLERY BOXES PROCESS PLAN 2

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Long Sides	Housing	Rye CNC - including jig for holding components	00:22:06	00:19:20	00:41:26
	Stopped Groove	N/A - Cut during above process	00:00:00	00:00:00	00:00:00
Short Ends	Through Groove	Spindle Moulder	00:06:48	00:03:40	00:10:28
Lid	Rebate	Spindle Moulder	00:07:35	00:06:30	00:14:05

Total time for all components	01:05:59
No. of Machines/tools used	2

TABLE 4.9 TEN JEWELLERY BOXES PROCESS PLAN 3

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Long Sides	Housing	Spindle Moulder	00:13:26	00:10:50	00:24:16
	Stopped Groove	Table router	00:07:50	00:08:10	00:16:00
Short Ends	Through Groove	Table router	00:00:00	00:04:10	00:04:10
Lid	Rebate	Spindle Moulder	00:07:35	00:06:30	00:14:05

Total time for all components	00:58:31
No. of Machines/tools used	2

TABLE 4.10 TEN JEWELLERY BOXES PROCESS PLAN 4

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Long Sides	Housing	Overhead router	00:09:30	00:11:50	00:21:20
	Stopped Groove	Overhead router	00:02:44	00:12:30	00:15:14
Short Ends	Through Groove	Overhead router	00:00:00	00:09:40	00:09:40
Lid	Rebate	Spindle Moulder	00:07:35	00:06:30	00:14:05

Total time for all components	01:00:19
No. of Machines/tools used	2

TABLE 4.11 TEN JEWELLERY BOXES PROCESS PLAN 5

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Long Sides	Housing	Rye CNC	00:22:06	00:19:20	00:41:26
	Stopped Groove	N/A - Cut during above process	00:00:00	00:00:00	00:00:00
Short Ends	Through Groove	Rye CNC	00:08:23	00:09:40	00:18:03
Lid	Rebate	Rye CNC	00:10:33	00:14:50	00:25:23

Total time for all components	01:24:52
No. of Machines/tools used	1

TABLE 4.12 TEN JEWELLERY BOXES PROCESS PLAN 6

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Long Sides	Housing	Overhead router	00:09:30	00:11:50	00:21:20
	Stopped Groove	Overhead router	00:02:44	00:12:30	00:15:14
Short Ends	Through Groove	Overhead router	00:00:00	00:09:40	00:09:40
Lid	Rebate	Table router	00:04:54	00:05:30	00:10:24

Total time for all components	00:56:38
No. of Machines/tools used	2

TABLE 4.13 TEN JEWELLERY BOXES PROCESS PLAN 7

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Long Sides	Housing	Table router	00:08:25	00:11:00	00:19:25
	Stopped Groove	Table router	00:07:50	00:08:10	00:16:00
Short Ends	Through Groove	Table router	00:00:00	00:04:10	00:04:10
Lid	Rebate	Spindle Moulder	00:07:35	00:06:30	00:14:05

Total time for all components	00:53:40
No. of Machines/tools used	2

TABLE 4.14 TEN JEWELLERY BOXES PROCESS PLAN 8

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Long Sides	Housing	Table router	00:08:25	00:11:00	00:19:25
	Stopped Groove	Table router	00:07:50	00:08:10	00:16:00
Short Ends	Through Groove	Panel Saw	00:01:44	00:33:10	00:34:54
Lid	Rebate	Panel Saw	00:02:58	00:05:30	00:08:28

Total time for all components	01:18:47
No. of Machines/tools used	2

For analysis and comparisons of the above results please refer to section 4.6.

4.5 Process Planning Trials for 1 Curved Shelf Unit

As with the jewellery box, the manufacture of the curved shelf was divided into components and then processing decisions to be carried out to each component. These are as follows:

TABLE 4.15 PROCESSING DECISIONS REQUIRED – CURVED SHELF

Component	Processing Decisions Required
Gables	Shape Gables
	Drill Gables
Convex Shelf	Shape Convex Shelf
	Drill Shelf
Concave Shelf	Shape Concave Shelf
	Drill Shelf

Again, each of the eight process planners were asked to describe in detail what equipment or methods they would use to produce the components firstly for one curved shelf, and then for a batch of ten curved shelves. Once more, the processes chosen for each component by the process planners were recorded. The components were then manufactured and timed by the author using each process plan.

On analysing the process plans, it became evident that some of the planners had chosen identical routes. In this instance process plans 1, 3, 5 & 6 returned matching routes. The following are the process plans produced by the process planners for the manufacture of one curved shelf and the recorded times for set-up and producing each component.

TABLE 4.16 ONE CURVED SHELF PROCESS PLANS 1,3,5 & 6

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Gables	Shape Gables	Weeke CNC	00:07:13	00:02:39	00:09:52
	Drill Gables	N/A Completed during shaping process	00:00:00	00:00:00	00:00:00
Concave Shelf	Shape Concave Shelves	Weeke CNC	00:04:53	00:01:50	00:06:43
	Drill Concave Shelves	N/A Completed during shaping process	00:00:00	00:00:00	00:00:00
Convex Shelf	Shape Convex Shelf	Weeke CNC - No set-up time. Same program used with curve inverted while first program running	00:00:00	00:01:50	00:01:50
	Drill Convex Shelf	N/A Completed during shaping process	00:00:00	00:00:00	00:00:00

Total time for all components	00:18:25
No. of Machines/equipment used	1

Figure 4.18 shows the gable after being processed on the Weeke CNC. The curved element was processed first and then the 4 holes were drilled vertically for the KD fittings.

Figures 4.19 and 4.20 show both the convex and concave shelves respectively. The curved element was first to be processed also then the horizontal holes were drilled to receive the threaded inserts. This sequence is controlled by the programmer for the machine.

FIGURE 4.18 GABLE ON THE WEEKE CNC

FIGURE 4.19 CONCAVE SHELF ON THE WEEKE CNC

FIGURE 4.20 CONVEX SHELF ON THE WEEKE CNC

TABLE 4.17 ONE CURVED SHELF PROCESS PLAN 2

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Gables	Shape Gables	Rye CNC	00:16:41	00:05:18	00:21:59
	Drill Gables	N/A Completed during shaping process	00:00:00	00:00:00	00:00:00
Concave Shelf	Shape Concave Shelves	Rye CNC	00:22:06	00:00:58	00:23:04
	Drill Concave Shelves	Horizontal Borer	00:03:03	00:00:48	00:03:51
Convex Shelf	Shape Convex Shelf	N/A Machined simultaneously with concave shelf from larger panel	00:00:00	00:00:00	00:00:00
	Drill Convex Shelf	Horizontal Borer	00:03:03	00:00:48	00:03:51

Total time for all components	00:52:45
No. of Machines/equipment used	2

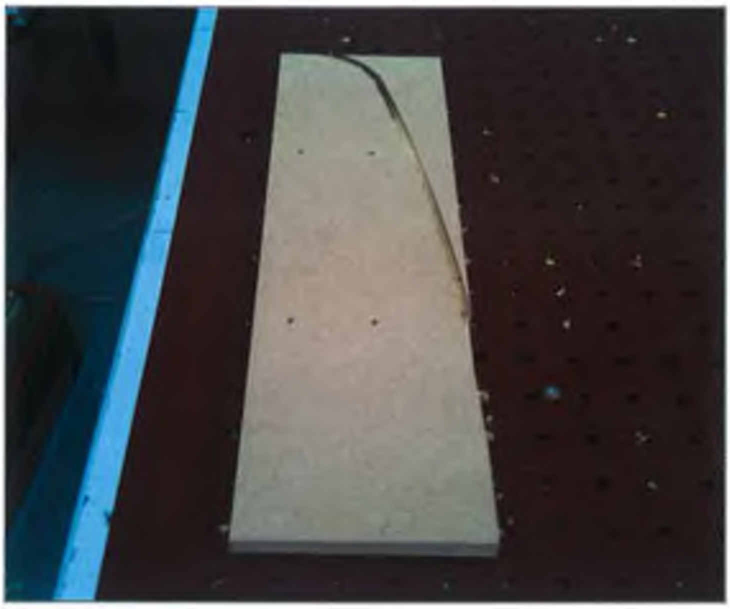

FIGURE 4.21 GABLE ON THE RYE CNC

Figure 4.21 shows a gable after being processed on the Rye CNC. It is worth noting here that the Rye is 16 years old (fig 4.21a), which in terms of technology is very much out of date. It has two routing heads and one vertical drilling head. All tool changes are manual. The Weeke on the other hand, has a multi-tool horizontal and vertical drilling head and an automatic 16 tool changer for the router head.

FIGURE 4.21A THE RYE CNC

TABLE 4.18 ONE CURVED SHELF PROCESS PLAN 4

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Gables	Shape Gables	Bandsaw out shape, finish to line with vertical sander, use as template to copy other gable on Overhead router	00:03:38	00:04:38	00:08:16
	Drill Gables	Cordless Drill	00:00:22	00:01:39	00:02:01
Concave Shelf	Shape Concave Shelves	Bandsaw and Vertical Sander - machined during set-up	00:03:16	00:00:00	00:03:16
	Drill Concave Shelves	Cordless Drill	00:00:24	00:01:48	00:02:12
Convex Shelf	Shape Convex Shelf	Bandsaw and Vertical Sander - machined during set-up	00:03:02	00:00:00	00:03:02
	Drill Convex Shelf	Cordless Drill	00:00:24	00:01:48	00:02:12

Total time for all components	00:20:59
No. of Machines/equipment used	4

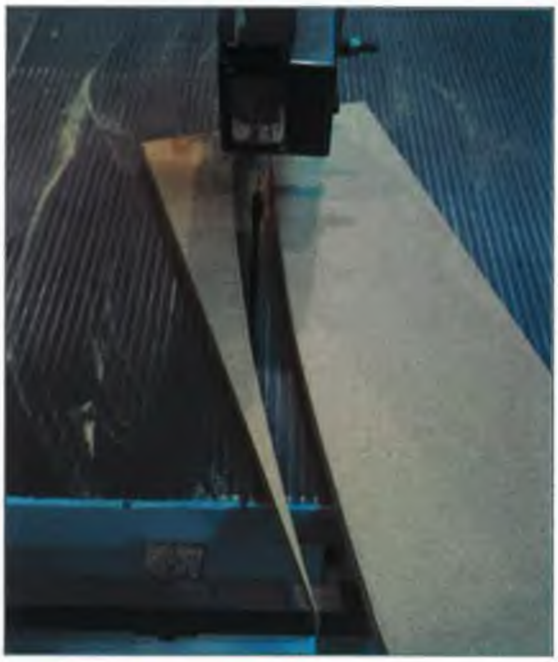

FIGURE 4.22 CUTTING WASTE ON BANDSAW

FIGURE 4.23 EDGE BEING CLEANED ON VERTICAL SANDER

Figure 4.22 above shows the main section of waste being cut away on the bandsaw. The shape was accurately marked according to the drawing with a pencil. Figure 4.23 shows the edge being sanded exactly to the pencil line. This requires a high level of operator skill. The completed gable is then used to mark the 2nd gable and the main section of waste is cut away on the bandsaw again. Figure 4.24 below shows both gables on the overhead router. A copying cutter is fitted to the machine. The bearing follows the contours of the first accurate gable and replicates this to the second gable. Both gables are temporarily held together with special purpose double sided tape.

FIGURE 4.24 COPY SECOND GABLE ON THE OVERHEAD ROUTER

TABLE 4.19 ONE CURVED SHELF PROCESS PLAN 7

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Gables	Shape Gables	Bandsaw out shape, finish to line with vertical sander, use as template to copy other gable on Table router	00:08:48	00:04:21	00:13:09
	Drill Gables	Vertical Drill	00:00:22	00:01:39	00:02:01
Concave Shelf	Shape Concave Shelves	Hand router with compass extension attached	00:09:29	00:01:36	00:11:05
	Drill Concave Shelves	Horizontal Borer	00:03:03	00:00:48	00:03:51
Convex Shelf	Shape Convex Shelf	N/A Machined simultaneously with concave shelf	00:00:00	00:00:00	00:00:00
	Drill Convex Shelf	Horizontal Borer	00:03:03	00:00:48	00:03:51

Total time for all components	00:33:57
No. of Machines/equipment used	6

FIGURE 4.25 CONVEX SHELF ON THE HORIZONTAL BORER

Figure 4.25 shows the convex shelf being drilled on the horizontal borer. The lateral distance between hole centres is controlled by a setting on the machine.

TABLE 4.20 ONE CURVED SHELF PROCESS PLAN 8

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Gables	Shape Gables	Hand router with compass extension attached to machine large curve. Finish small curve with bandsaw and vertical sander	00:14:04	00:04:17	00:18:21
	Drill Gables	Vertical Drill	00:00:22	00:01:39	00:02:01
Concave Shelf	Shape Concave Shelves	Hand router with compass extension attached	00:09:29	00:01:36	00:11:05
	Drill Concave Shelves	Horizontal Borer	00:03:03	00:00:48	00:03:51
Convex Shelf	Shape Convex Shelf	N/A Machined simultaneously with concave shelf from larger panel	00:00:00	00:00:00	00:00:00
	Drill Convex Shelf	Horizontal Borer	00:03:03	00:00:48	00:03:51

Total time for all components	00:39:09
No. of Machines/equipment used	5

For analysis and comparisons of the above results please refer to section 4.6.

4.6 Process Planning Trials for 10 Curved Shelf Units

Upon completion of the process plans for 1 curved shelf, the eight process planners repeated the exercise with a batch quantity of 10 curved shelves. The four process planers who opted to use the Weeke CNC for producing 1 curved shelf unit chose the same option for a batch quantity of 10. Following are the process plans produced by the process planners for the manufacture of 10 curved shelves and the recorded times for set-up and producing all components.

TABLE 4.21 TEN CURVED SHELVES PROCESS PLANS 1, 3, 5 & 6

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Gables	Shape Gables	Weeke CNC	00:07:13	00:26:30	00:33:43
	Drill Gables	N/A Completed during shaping process	00:00:00	00:00:00	00:00:00
Concave Shelf	Shape Concave Shelves	Weeke CNC	00:04:53	00:18:20	00:23:13
	Drill Concave Shelves	N/A Completed during shaping process	00:00:00	00:00:00	00:00:00
Convex Shelf	Shape Convex Shelf	Weeke CNC - No set-up time. Same program used with curve inverted while first program running	00:00:00	00:18:20	00:18:20
	Drill Convex Shelf	N/A Completed during shaping process	00:00:00	00:00:00	00:00:00

Total time for all components	01:15:16
No. of Machines/equipment used	1

TABLE 4.22 TEN CURVED SHELVES PROCESS PLAN 2

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Gables	Shape Gables	Rye CNC	00:16:41	00:53:00	01:09:41
	Drill Gables	N/A Completed during shaping process	00:00:00	00:00:00	00:00:00
Concave Shelf	Shape Concave Shelves	Rye CNC	00:22:06	00:09:40	00:31:46
	Drill Concave Shelves	Horizontal Borer	00:03:03	00:08:00	00:11:03
Convex Shelf	Shape Convex Shelf	N/A Machined simultaneously with concave shelf from larger panel	00:00:00	00:00:00	00:00:00
	Drill Convex Shelf	Horizontal Borer	00:03:03	00:08:00	00:11:03

Total time for all components	02:03:33
No. of Machines/equipment used	2

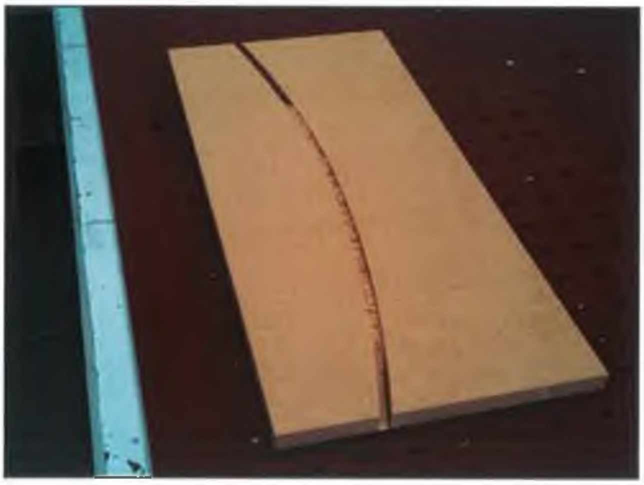

FIGURE 4.26 CURVED SHELVES ON THE RYE

Figure 4.26 shows both the convex and concave shelves being cut simultaneously from 1 panel on the Rye CNC.

TABLE 4.23 TEN CURVED SHELVES PROCESS PLAN 4

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Gables	Shape Gables	Make the first component with the same technique as for one unit and use this as a jig template for the spindle moulder. Remove most of the waste on the bandsaw and clean the edges with the jig and spindle moulder.	00:18:13	00:26:20	00:44:33
	Drill Gables	Make one accurately with cordless drill and use it as an overlay to mark the position for the other gables and drill.	00:02:22	00:08:20	00:10:42
Concave Shelf	Shape Concave Shelves	Make the first with the same technique as for one unit and use as a template for the remaining shelves on the spindle moulder	00:16:44	00:21:58	00:38:42
	Drill Concave Shelves	Make an overlay with exact position of holes and use as a template for drilling all shelves	00:02:04	00:10:10	00:12:14
Convex Shelf	Shape Convex Shelf	Make the first with the same technique as for one unit and use as a template for the remaining shelves on the spindle moulder	00:17:39	00:00:00	00:17:39
	Drill Convex Shelf	Same jig as for concave shelves	00:00:00	00:10:10	00:10:10

Total time for all components	02:14:00
No. of Machines/equipment used	4

FIGURE 4.27 JIG TO PRODUCE GABLE ON THE SPINDLE MOULDER

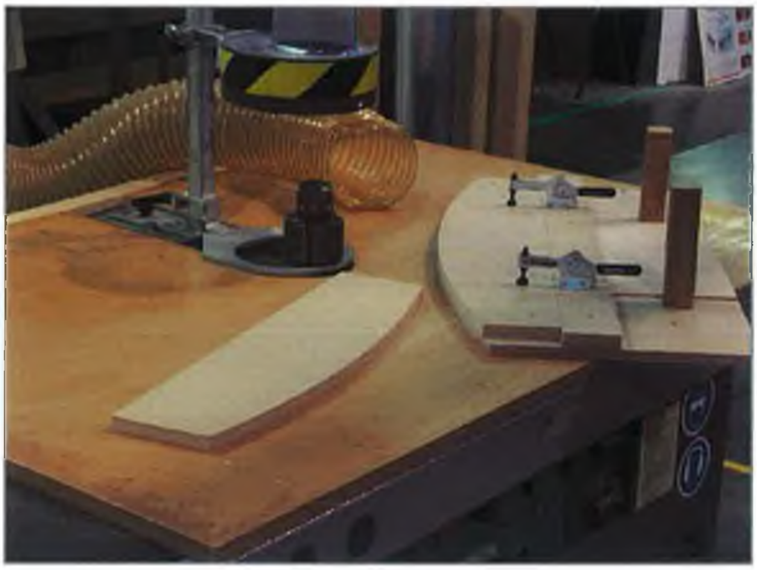

FIGURE 4.28 JIG TO PRODUCE CONVEX SHELF ON THE SPINDLE MOULDER

Figures 4.27 and 4.28 above show two specially constructed work holding jigs for processing the gables and the convex shelves. The cutter used is a straight edge shear cutter with a ring fence. The ring fence is mounted below the cutter and is set exactly in line with the edge of the cutter. The jig follows the ring fence and the cutter trims the panel to the exact profile of the jig. The construction time for work holding jigs have been included in the process plans.

TABLE 4.24 TEN CURVED SHELVES PROCESS PLAN 7

Component	Processes Required	Process Chosen	Set-up Time	Processing Time	Overall Time
Gables	Shape Gables	Make jig for spindle moulder	00:18:13	00:26:20	00:44:33
	Drill Gables	Vertical Pillar Drill	00:00:42	00:19:40	00:20:22
Concave Shelf	Shape Concave Shelves	Make jig for spindle moulder	00:16:44	00:21:58	00:38:42
	Drill Concave Shelves	Horizontal Borer	00:03:03	00:08:00	00:11:03
Convex Shelf	Shape Convex Shelf	Make jig for spindle moulder	00:17:39	00:21:58	00:39:37
	Drill Convex Shelf	Horizontal Borer	00:03:03	00:08:00	00:11:03

Total time for all components	02:45:20
No. of Machines/equipment used	6

TABLE 4.25 TEN CURVED SHELVES PROCESS PLAN 8

Process Plan 8

Component	**Processes Required**	**Process Chosen**	**Set-up Time**	**Processing Time**	**Overall Time**
Gables	Shape Gables	Make jig for table router	00:25:34	00:23:00	00:48:34
	Drill Gables	Vertical Drill	00:00:42	00:19:40	00:20:22
Concave Shelf	Shape Concave Shelves	Make jig for table router	00:18:44	00:09:40	00:28:24
	Drill Concave Shelves	Horizontal Borer	00:03:03	00:08:00	00:11:03
Convex Shelf	Shape Convex Shelf	Make jig for table router	00:17:34	00:21:58	00:39:32
	Drill Convex Shelf	Horizontal Borer	00:03:03	00:08:00	00:11:03

Total time for all components	02:38:58
No. of Machines/equipment used	6

FIGURE 4.29 CONCAVE SHELF JIG ON THE TABLE ROUTER

Figure 4.29 shows a work holding jig for producing the concave shelves on the table router. The cutter used is a copying cutter, and as before, follows the shape of the jig to reproduce that pattern to the shelf.

Figure 4.30 below shows the first stage of the jig construction. A compass arm is attached to the base of a hand router and the router acts as a pendulum. The cut is performed in a number of stages until it has completely cut through. This panel is then used as the base board of the jig.

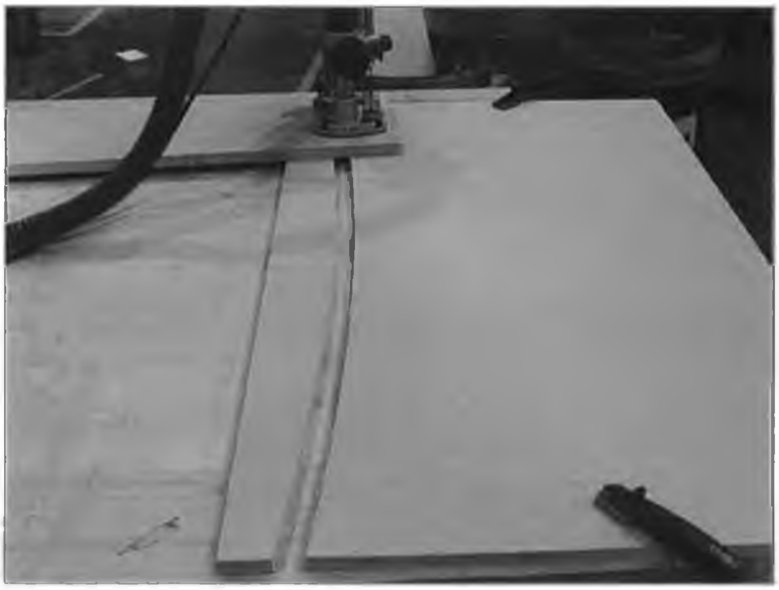

FIGURE 4.30 CONCAVE SHELF JIG BEING CONSTRUCTED

For analysis and comparisons of the above results please refer to section 4.6 to follow.

4.7 Process Planning Trials Analysis

The purpose of the process trials was to determine the effectiveness of process planning decisions being made by experienced users in manufacturing a component or number of components. With the results obtained from the process planning trials it became clear that depending on who makes the process planning decisions, the time difference in a products fabrication can vary considerably.

The graph shown below in figure 4.31 illustrates the overall total set-up and processing time for all process plans given by each planner for the manufacture of one jewellery box. Process plan 1 is the most time efficient method of producing the jewellery box. Process plan 2 is the least time efficient method taking over 2.5 times longer.

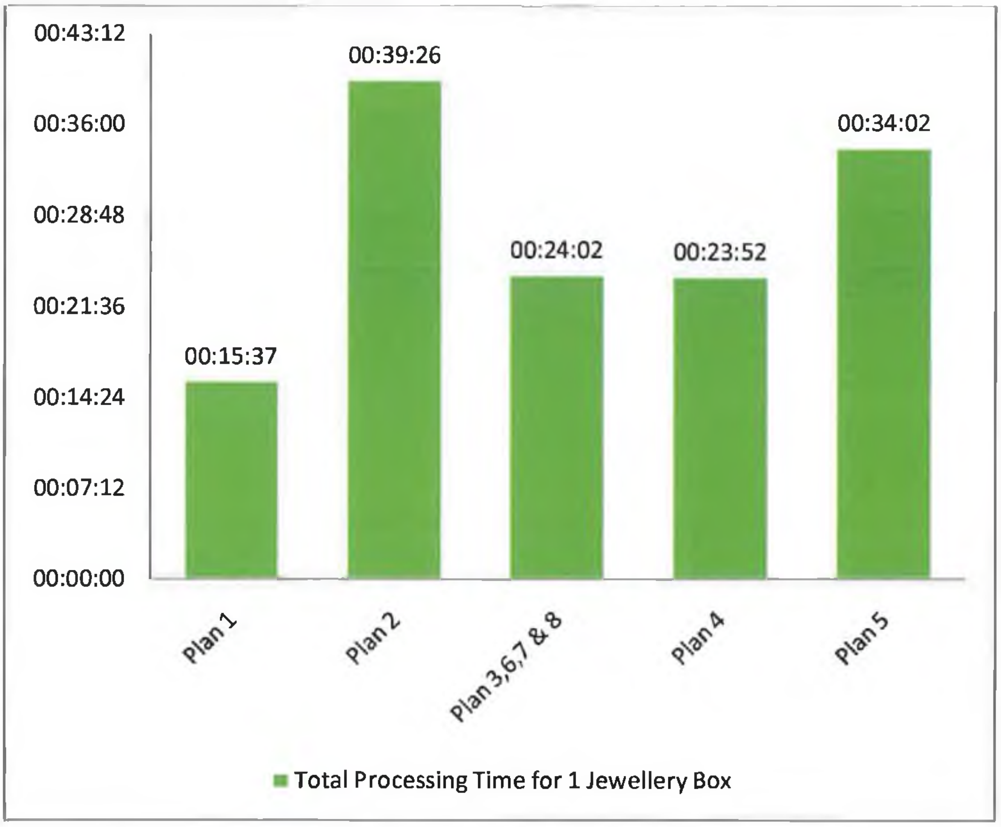

FIGURE 4.31 TOTAL PROCESSING TIME PER PROCESS PLAN FOR 1 JEWELLERY BOX.

Another factor which became apparent as a result of the trials is the number of machines or tools required to complete the jewellery box. This varied depending on which set of process plans were followed. Process plan 1 used only one machine to process all parts i.e. the Weeke CNC. In contrast, process plan 5 used four processes or tools i.e. table saw, overhead router, spindle moulder and hand chisel. Depending on the manufacturing facility this could potentially cause a materials handling issue contingent on the position of the machines, relative to each other and time taken moving material between processes. Figure 4.32 below shows the number of machines/tools used per process plan.

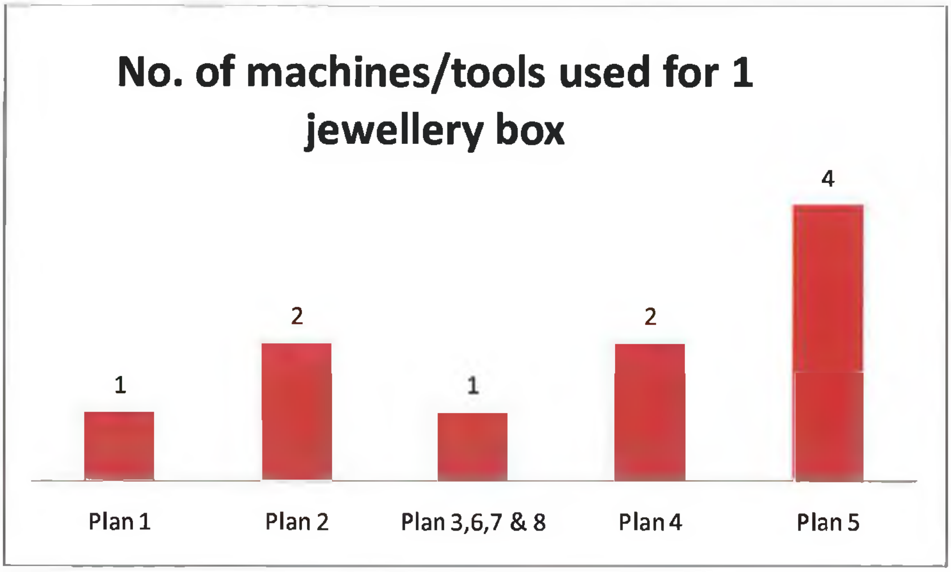

FIGURE 4.32 MACHINES/TOOLS USED PER PROCESS PLAN FOR 1 JEWELLERY BOX.

On analysing the results obtained from the process planning trials for a batch quantity of ten jewellery boxes it was surprising to note that when the batch size was increased, five of the planners changed one or more processes compared to their original plan for one jewellery box. Subsequently this meant that instead of five separate process routes from eight planners initially, this time there were eight different process plans from eight planners. Some of the differences between plans were small but they were different. See table 4.26 below.

TABLE 4.26 PROCESS PLAN CHANGES FOR A BATCH OF 10 JEWELLERY BOXES.

Process plan changes for a batch of 10 Jewellery Boxes	
	Same Process Route as for 1 Jewellery Box
Process Plan 1	Yes
Process Plan 2	Yes
Process Plan 3	Different Route
Process Plan 4	Yes
Process Plan 5	Different Route
Process Plan 6	Different Route
Process Plan 7	Different Route
Process Plan 8	Different Route

Taking the above into consideration it seems that some of the process planners have a preference for certain processes. On enquiring further with the process planners themselves, it was found that this was based on their experience with a particular process and also their fluency with that process, which is aided by experience. For example the planners who chose not to use the CNC commented that they did not have the experience or expertise to do so.

Therefore, when process planning, a person's reason for choosing a certain process is likely to be influenced by their experience with that process which in turn may be influenced by the training they received on that process. The more concise the training, the more likely they will be drawn to that process as a solution. The more they use that process, the more experienced they become.

It was evident when documenting the process plans, as being described by the process planners, that certain people were 'drawn' to certain processes as their first solution. If it could be used it was, and if not they explored other options. As an example Process Planner 4 is known to the author as being highly experienced and skilled on the spindle moulder. When process planning the jewellery box they only chose the spindle moulder for removing the rebate on the lid. However, verbally they commented that "that process could not be done out on the spindle moulder so I would use the x machine" and made an alternative process selection.

Process Planner 1 is known in GMIT Letterfrack as the most experienced user of the Weeke CNC. Perhaps it was no coincidence that he chose this machine for all processes in all trials. On preparing the process plans for the jewellery box they recognised that the components were too small to be held on the CNC. Instead of choosing an alternative process, they performed a mental re-design of the components and requested that the two long sides be prepared as one panel, thus allowing the piece to be held securely on the bed of the CNC. As part of the processing function both long sides were produced from the same panel and then divided into two long sides (see figure 4.8). This is significant because it highlights how the design of a product can affect how it is produced and, how the re-design of components can make it more suitable to a particular process.

A further example can be demonstrated where process planner 2 is known in GMIT Letterfrack as the most experienced user of the Rye CNC. They chose the Rye for removing the housing and stopped groove from the long sides for both one and ten jewellery boxes. When producing one box a special work holding jig (see figure 4.11) was required to be made. This brought the set-up time to 22 minutes 6 seconds, more than twice the set-up time for any other comparable process chosen by the other planners. They are very experienced with using the spindle moulder, the overhead router, hand router, table router, etc. and could have chosen these easily but did not. It seems that because they use the Rye so regularly, they are biased towards it as a first stop for manufacturing solutions. Seemingly, the same approach as process planner 1 with the Weeke CNC. It is possible that they feel they will be more efficient doing it that way as they are so competent on that machine.

GMIT Letterfrack is considered a 'centre of excellence' for the furniture and wood products industry. It is an intriguing observation to note that the students learning outcomes and wood machining skills could vary exponentially, based on which lecturer has been involved in teaching their practical learning module. Hypothetically, if this was a classroom situation and a student approached the eight technical staff concerned with a working drawing and asked for advice on how best to make a batch of 10 jewellery boxes, they would receive 8 differing answers. Currently, one lecturer generally takes one group for their practical training module per year. If that lecturer has a preference towards using a certain process then the likelihood is that they will be passing on those preferences to the group of students they are teaching. Now it seems we have groups of students graduating with preferences for different processes based on the lecturer from whom they received their training, while attending GMIT Letterfrack.

It is beyond the scope of this project to investigate the training and experiences of the process planers and whether or why it relates to the decisions they returned. They all had the same processing facilities available to them but for whatever reasons they have chosen to use their preferred processes. When questioned, no evidence showed that anyone approached it from a time or cost benefit point of view.

When 1 jewellery box was being manufactured process plan 1 was the most time efficient. When the batch size was increased to 10 however, the outcome was very different. As seen in figure 4.33, process plan 7 is now the most time efficient at 53 minutes and 38 seconds. Process plans 1, 3, 4 and 6 are only separated by less than 4 minutes.

This is a very different outcome to the original trials for one box. Process plans with longer set-up times and shorter processing times performed better with a larger batch size. This indicates that CNC technology may be flexible in relation to product changes and short processing cycles but can be outperformed by traditional machines for increased batch sizes.

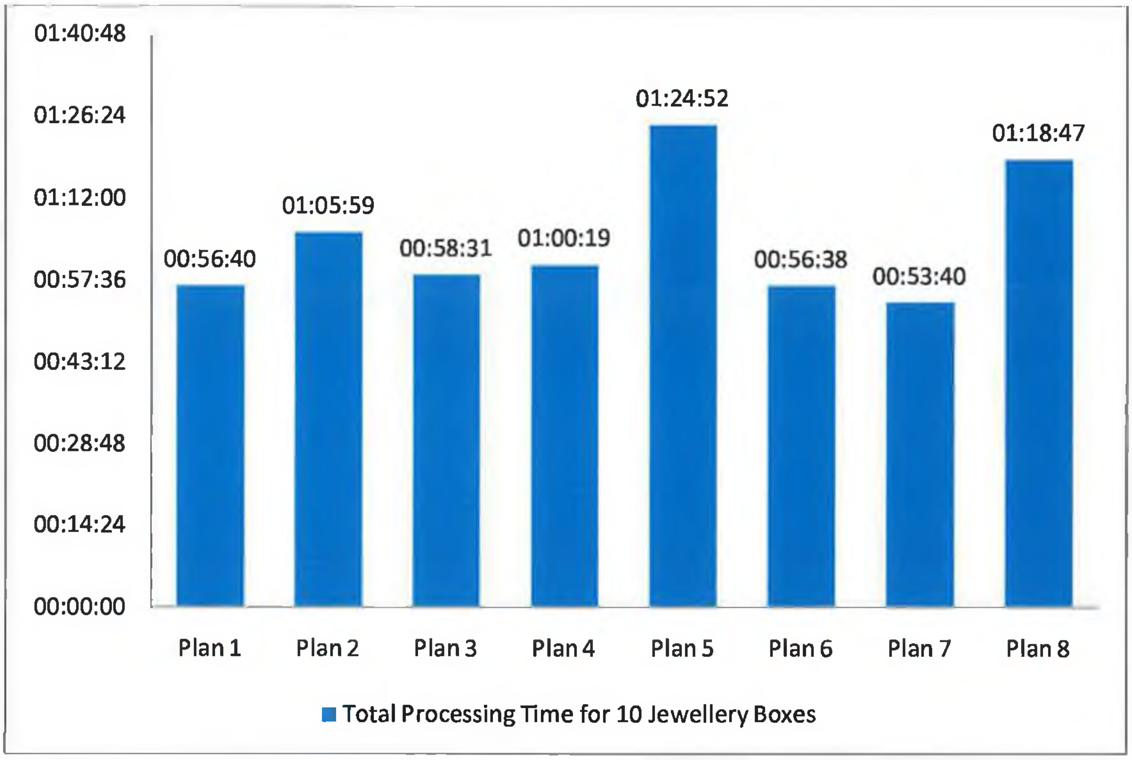

FIGURE 4.33 TOTAL PROCESSING TIME PER PROCESS PLAN FOR 10 JEWELLERY BOXES.

The graph shown below in figure 4.34 illustrates the overall total set-up and processing time for all process plans given by each planner for the manufacture of one curved shelf. The same plan was submitted by planners 1, 3, 5 and 6 who all chose to use the Weeke CNC. The results showed that this route was the most effective method of producing one curved shelf in relation to time, again indicating towards positive results for the CNC with short cycles. However, plan 4 used traditional machines and only took 2 minutes 34 seconds longer to finish. For a batch size of one, this seems not that significant, however, for larger batch sizes it could potentially be very substantial.

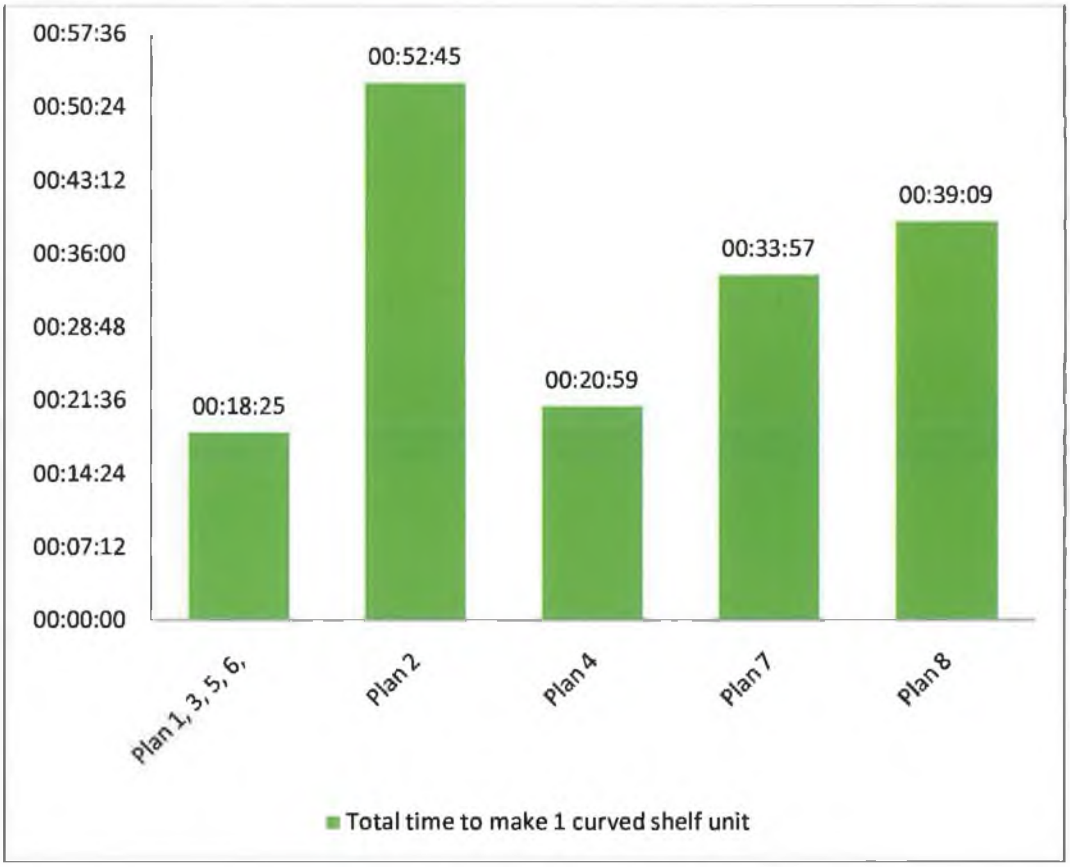

FIGURE 4.34 TOTAL PROCESSING TIME PER PROCESS PLAN FOR 1 CURVED SHELF.

Figure 4.35 shows the number of machines/tools used per process plan for one curved shelf. Again worth noting are the number of machines or tools required to complete the curved shelf depending on which set of process plans were followed. Process plans 1, 3, 5 and 6 used only one machine to process all parts i.e. the Weeke CNC. In contrast, process plan 8, taking more than twice as long used six processes or tools. Yet again depending on the manufacturing facility this could potentially cause a materials handling delay moving the components between processes.

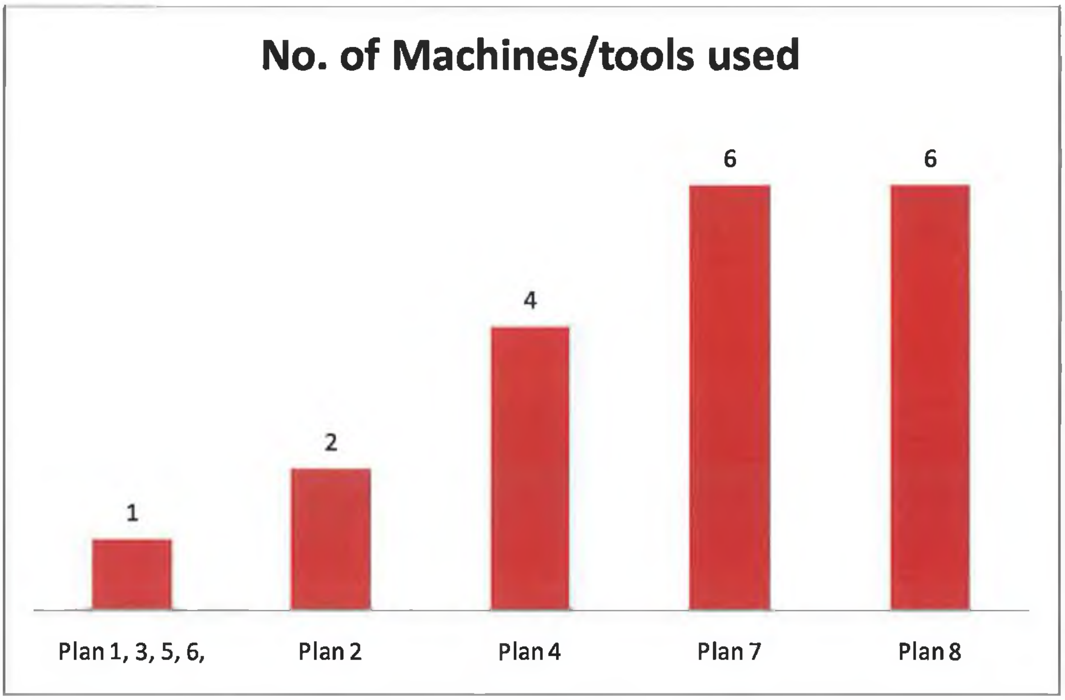

FIGURE 4.35 MACHINES/TOOLS USED PER PROCESS PLAN FOR 1 CURVED SHELF.

On examining the results obtained from the process planning trials for a batch quantity of 10 curved shelves, some of the process planners remained with their original routes and others changed. This time 5 of the planners kept with their original choice and 3 changed their processing options for an increased batch size. See table 4.27 below.

TABLE 4.27 PROCESS PLAN CHANGES FOR BATCH OF 10 CURVED SHELVES.

Process plan changes for a batch of 10 Curved Shelves	
	Same Process Route as for 1 Curved Shelf
Process Plan 1,3,5, 6	Yes
Process Plan 2	Yes
Process Plan 4	Different Route
Process Plan 7	Different Route
Process Plan 8	Different Route

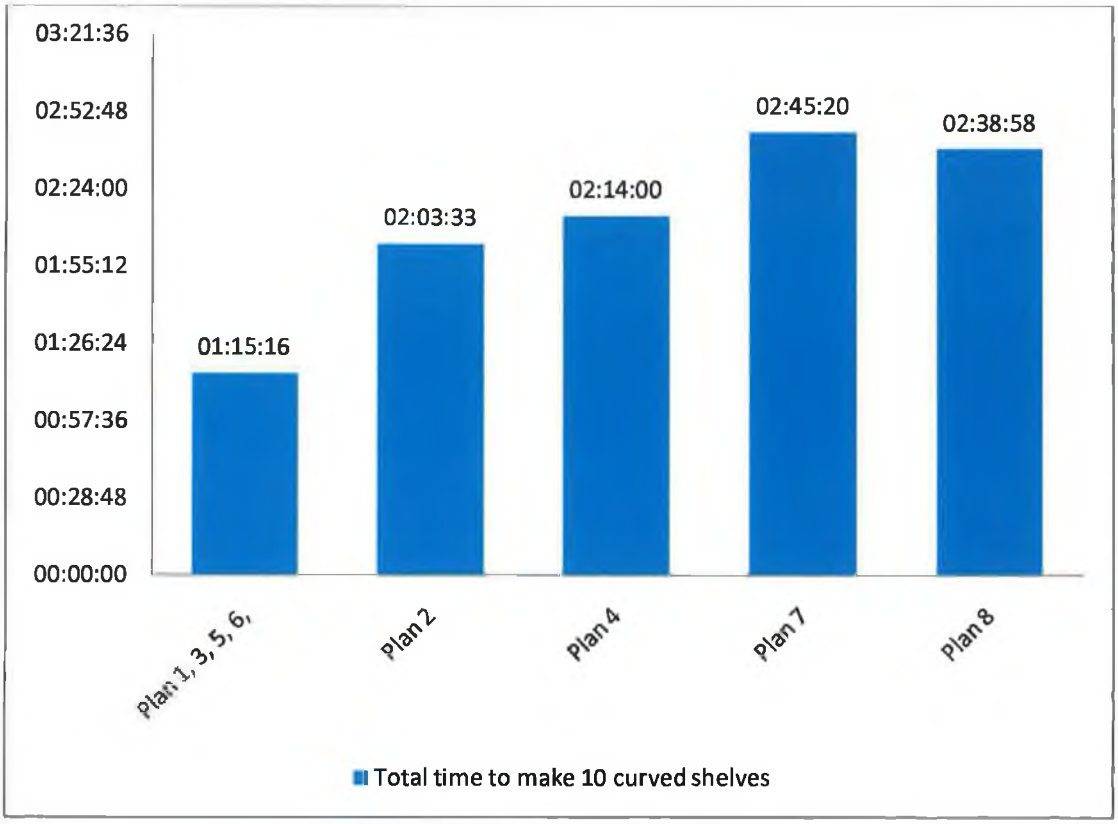

FIGURE 4.36 TOTAL PROCESSING TIME PER PROCESS PLAN FOR 10 CURVED SHELVES.

Notably, this time when the batch size was increased, the process plans using the Weeke CNC, still outperformed the other process plans as it did when producing 1. For the jewellery boxes it outperformed the other process plans when producing 1 box but was only on a par with many of the other routes when producing 10 jewellery boxes. See total times above in figure 4.36.

On investigating why this could be so, the answer seems to be centred around the design of the shelving system. The unit is assembled using KD fittings. This requires both vertical and horizontal drilling which is an inbuilt function of the Weeke CNC. If the shelving unit were made from solid wood and assembled using a more traditional means, e.g. a twin wedged mortise and tenon, then the components would not be able to be produced in their entirety on the Weeke CNC. The overall look of the shelving unit would be the same, but the method of construction would be different. This identifies how the person responsible for the design of the construction of the product, not the concept or the form, effectively is creating process planning decisions. If the designer used solid wood instead of MDF, and twin wedged mortise and tenons instead of KD fittings and the process trials were re-run, it would be likely to have a sizable affect on the process plans. It would require a certain amount of processing on more traditional machines as it is beyond the capabilities of the CNC equipment. This highlights the influence that the designer or technical office staff producing drawings or constructional details can have over the process route chosen. It also indicates that informal process planning decisions are being made, perhaps unknowingly, by technical office staff before the information gets to the manufacturing stage. Surely this decision procedure should be part of a process planning methodology.

4.8 Conclusions

Based on the information gathered from the process trials, it is very evident that a structure is needed to assist the process planning procedure. The current method of choosing the process, because of familiarity, returns too many variations. The trials have highlighted how the variability between process planners may be vast, but more importantly could result in either positive or negative outcomes for a company depending on who chooses the processes and how long it takes. The process planning trials have highlighted a number of possible issues:

- People have preferences and seem to be biased towards certain processes i.e. decisions are being based on people's preferences for using a particular process as opposed to the efficiency of that process.
- These preferences may initiate from the training they received and the experience they have on that process.
- The design and construction of a product has a sizeable influence on the process chosen.
- CNC technology is flexible in relation to product changes and short processing cycles but is comparable to traditional machines for larger batch sizes. However, this appears to be directly related to the construction of the product.

5. Process Planning Guidelines and Methodology

5.1 Introduction

This chapter takes the findings of previous chapters and proposes the establishment of a process planning methodology. Process planning guidelines have been developed in spreadsheet format, to encourage the person responsible for process planning, to contemplate other processing options. These guidelines were applied in a sample exercise using spreadsheets, to one of the products used for the process planning trials, in order to demonstrate an improved decision process.

Process planning guidelines are integrated into an overall methodology that combines process decisions/choices made implicitly and explicitly throughout the cycle. There is no attempt to disguise that the main reason for such a system is to help designers and engineers to design for CNC manufacture, while it will also help with the design for manufacture and process planning for other processes.

5.2 Process Planning Guidelines Approach

The system will be spreadsheet based, but will use the principles of a case-based expert system as discussed earlier, (Humm et al. 1991). Hall (1997) developed a spreadsheet based tool, for 'reactive' process planning and scheduling, that "*allows differing manufacturing environments to be tested and, using a range of decision making criteria, optimises product flow to make full use of the manufacturing system in a variety of circumstances*". Hall (1997) used a wide set of weighted parameters including resource availability, resource desirability, resource utilisation, materials, throughput, due dates, product value and goodwill, operation capability, set-up time, operations cost, and quality. While this tool served a different purpose to what is proposed here, the principle is similar.

It was decided to focus the guidelines on one of the products used for the process trials as there was already real-time data gathered for the variety of processing options. This is considered as the first step in creating a 'knowledge base' for a process planning decision system. When processes are performed the knowledge-base becomes more accurate. This was addressed by Humm et al (1991) where he concluded that a knowledge base grows with experience i.e. the more inputs the more accurate the system becomes. By focusing the system on the process required for a component to become closer to completion, it allows for a user to identify the various processing options that are available. This is opposed to having the system focused towards the processing capability of certain equipment.

The author considered the second approach would be more difficult to present the information in a manner that would be useful and useable to a process planner as there are almost infinite variables. By focusing on the processes that are carried out it becomes more specific, easier to identify processing options and removes the burden of generating process planning scenarios that may not be required. In summary, the guidelines are centred on the processes being performed to components, as opposed to analysing the variety of functions particular machinery or equipment can perform.

5.2.1 Process Planning Guidelines Sample

In developing the process planning guidelines, the jewellery box used earlier in the process planning trials was used, because real processing data exists for the alternative processing options. The product was divided into components and then processing decisions to be carried out to each component, just as with the original process trials. See table 4.1 earlier.

Firstly, to demonstrate how the process planning spreadsheet works, screen shots and explanations of the inputs which a user may select from are displayed. Following from this explanation is a full sample of the spreadsheet being applied to the jewellery box to demonstrate the recommended process plan for its manufacture.

The spreadsheet and supporting relevant documentation has been supplied on a CD accompanying this thesis. The spreadsheets use a lot of programming commands such as; VLOOKUP, IF, CONCATENATE, COUNTIF, etc. It is important to note that the author is not a computer programmer. While the spreadsheet works well, it is not a full functioning process planning system. The purpose of the sample is show that such system could work if a professional system was developed.

To use the spreadsheet, the user needs to input the relevant data pertinent to the product they are making. Figure 5.1 shows a screen shot of part of the spreadsheet. The column on the left lists parameters relevant to the processing of the part or component. Adjoining this column are the part descriptors which need to be selected by the user. When each corresponding cell is selected, a drop down list of options becomes available. Figure 5.1 shows the options available for part shape, i.e. linear, linear and curved, curved or compound curved. The user selects the most appropriate descriptor for the part being processed. This process is repeated for the remaining part descriptors choosing from the most appropriate selection available in the drop down list. Figure 5.2 shows the material options as a further example of the drop down lists.

In the adjacent cells are guidelines relating to a specific machine and its capability of performing the process required. The guidelines list specific instructions, if applicable, e.g. 'require a work holding jig to be fabricated' or 'no issue' and so on.

Y for yes, is entered into the appropriate cell if the machine is not affected by constraints identified in the part descriptors. If however the machine is affected by constraints from the part descriptors e.g. a certain tool is not available, or a machine is not suitable to processing a certain type of material, then N for no is entered. This rules the particular machine out for processing the component. From the remaining machines the set-up time and processing time is calculated. This is taken from the knowledge base which operates in the background of the spreadsheet. Existing data from previous times where the process had been run and recorded have been entered. Also, as new processes are performed, they are recorded and entered into the knowledge base. This means the spreadsheet will calculate the set-up and processing times averaged from previous recordings of running that actual process.

		Spindle Moulder		Overhead Router	
Parameters:	Part Descriptors	Yes/ No	Guidelines	Yes/ No	Guidelines
Part Shape	Linear		No Issue	Y	No Issue
Size	Linear Linear & Curved Curved Compound Curved		Requires a work holding Jig to be fabricated	Y	No Issue
Weight	Light - 1		No Issue	Y	No Issue
Handling capability	Unsafe to handle - Workholding jig required	Y	No Issue	Y	Must be fed with a pushstick
Quantity required / Batch size	6 to 10	Y	No Issue	Y	No Issue
Material	Solid Hardwood	Y	No Issue	Y	No Issue
Tooling	5mm Grooving cutter	Y	5mm grooving cutter available	Y	5mm router cutter available
Precision required	Exact to specification	Y	No issue if set-up correctly	Y	No issue if set-up correctly
Machine suitable for Process			Yes		Yes
Expected Set-up time			00:06:48		00:02:44
Expected Unit Processing time			00:00:22		00:00:58
Estimated Processing time			00:09:32		00:25:08
Total Estimated			00:16:20		00:27:52
			Recommend Option		

FIGURE 5.1 SAMPLE OF PROCESS PLANNING SPREADSHEET SHOWING PART SHAPE OPTIONS.

		Spindle Moulder		Overhead Router	
Parameters:	Part Descriptors	Yes/ No	Guidelines	Yes/ No	Guidelines
Part Shape	Linear	Y	No Issue	Y	No Issue
Size	Very Small - less than 300mm	Y	Requires a work holding Jig to be fabricated	Y	No Issue
Weight	Light - 1kg - 2kg	Y	No Issue	Y	No Issue
Handling capability	Unsafe to handle - Workholding jig required	Y	No Issue	Y	Must be fed with a pushstick
Quantity required / Batch size	6 to 10	Y	No Issue	Y	No Issue
Material	Solid Hardwood	Y	No Issue	Y	No Issue
Tooling			5mm grooving cutter available	Y	5mm router cutter available
Precision required			No issue if set-up correctly	Y	No issue if set-up correctly

Medium Density Fibreboard (M
High Denisty Fibreboard (HDF
Chipboard
Melamine Faced Chipboard (M
Solid Hardwood
Solid Softwood

	Spindle Moulder	Overhead Router
Machine suitable for Process	Yes	Yes
Expected Set-up time	00:06:48	00:02:44
Expected Unit Processing time	00:00:22	00:00:58
Estimated Processing time	00:09:32	00:25:08
Total Estimated	00:16:20	00:27:52
	Recommend Option	

FIGURE 5.2 SAMPLE OF PROCESS PLANNING SPREADSHEET SHOWING MATERIAL OPTIONS.

When a user wants to add a new process other than those already listed, they must go to the 'Drop down info' tab on the spreadsheet (see figure 5.3), and under the process description column, right click within the current range and choose insert cell. This will then spread the range.

When adding recorded times for new or existing processes, this is added in the 'knowledge base' tab in the spreadsheet, again see figure 5.3. The information is added below the existing rows of information. When finished it is very important to alphabetically sort the rows based on column E which is titled Process Part Code. This is because the calculation uses the VLOOKUP command and if not sorted will return incorrect information.

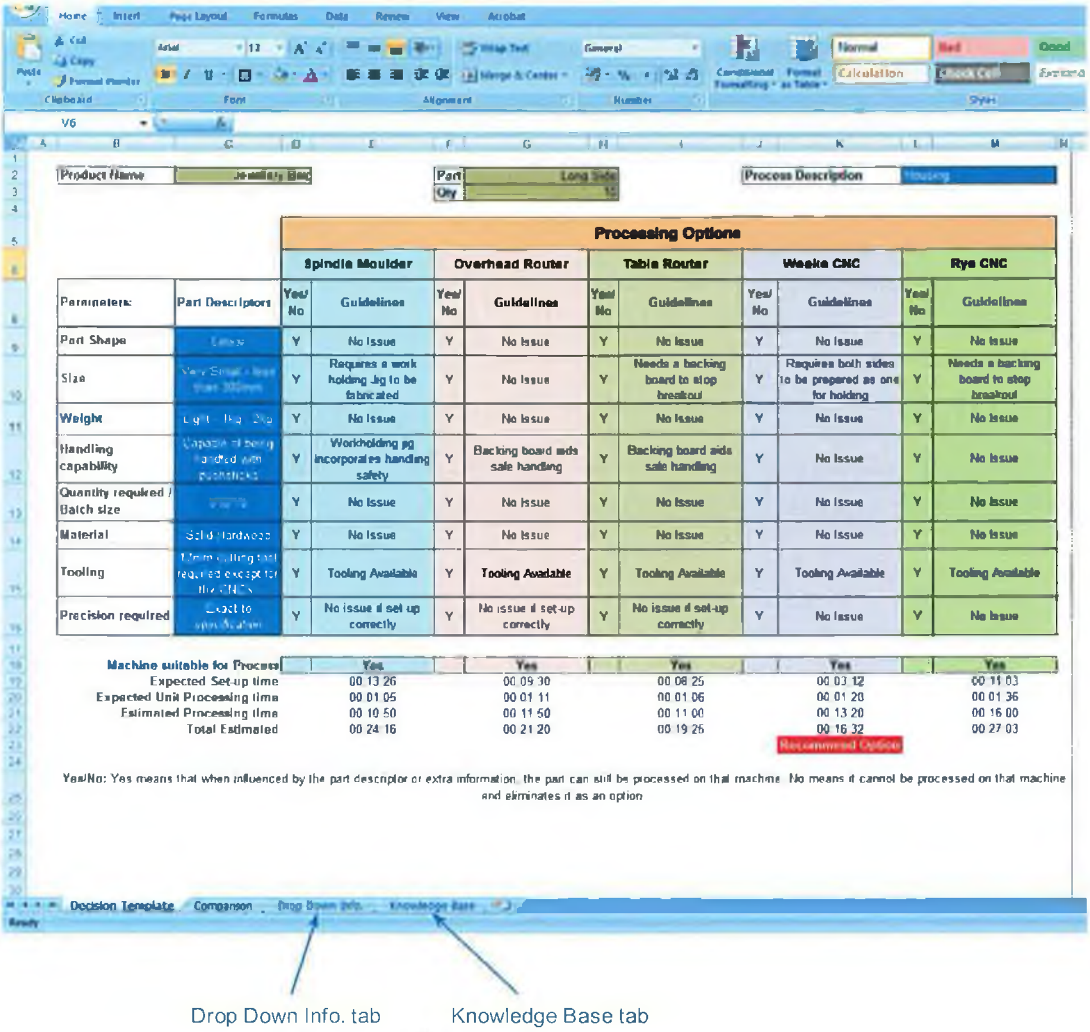

FIGURE 5.3 SAMPLE OF PROCESS PLANNING SPREADSHEET SHOWING TABS.

The total time taken for each machine to carry out the process is the critical output. The spreadsheet automatically highlights the most time efficient processing option.

An important factor to note is that some components may require more than one process to reach completion. For example the long sides for the jewellery box require a housing and a stopped groove. Referring to Hodgson & Pitts (1991) ideally, processing should aim to have a single tool set-up, or if that is not possible, a single machine with the minimum number of tool set-ups. It is envisaged that an expert system would have the ability to cross-reference parts from the same product, and create the overall process plan, for all components, on the best processing route for groups of parts, as opposed to just a single component. It is beyond the scope of this research to analyse any associated advantages or disadvantages of single tool set-ups.

The spreadsheet currently does not automatically summarise the process plan suggestions for all processes onto one sheet and in the example to follow has been created manually. This can be achieved by developing a macro to take a copy of the data from the decision template and saving it to another worksheet to give all the options for a product. However this level of programming is further than the author thought necessary for this thesis.

Tables 5.1 to 5.4 to follow show the process planning guidelines for the jewellery box processes, i.e. housing, stopped groove, through groove and rebate. Table 5.5 shows the process plan suggestions for producing the jewellery box. Significantly, the total processing time for producing a batch of ten jewellery boxes, if following the process plans produced by the spreadsheets is 47 minutes and seven seconds. Based on the best process plan produced by the eight process planers, the total processing time was 53 minutes and 40 seconds, 14% longer than results from the guidelines spreadsheet.

TABLE 5.1 PROCESS PLANNING GUIDELINES FOR HOUSING

Product Name	Jewellery Box	Part	Long Side	Process Description	Housing
		Qty	10		

		Processing Options									
		Spindle Moulder		Overhead Router		Table Router		Weeke CNC		Rye CNC	
Parameters:	Part Descriptors	Yes/ No	Guidelines	Yes/ No	Guidelines	Yes/ No	Guidelines	Yes/ No	Guidelines	Yes/ No	Guidelines
Part Shape	Linear	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Size	Very Small - less than 300mm	Y	Requires a work holding Jig to be fabricated	Y	No Issue	Y	Needs a backing board to stop breakout	Y	Requires both sides to be prepared as one for holding	Y	Needs a backing board to stop breakout
Weight	Light - 1kg - 2kg	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Handling capability	Capable of being handled with pushsticks	Y	Workholding jig incorporates handling safety	Y	Backing board aids safe handling	Y	Backing board aids safe handling	Y	No Issue	Y	No Issue
Quantity required / Batch size	6 to 10	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Material	Solid Hardwood	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Tooling	12mm cutting tool required except for the CNC's	Y	Tooling Available	Y	Tooling Available	Y	Tooling Available	Y	Tooling Available	Y	Tooling Available
Precision required	Exact to specification	Y	No issue if set-up correctly	Y	No issue if set-up correctly	Y	No issue if set-up correctly	Y	No Issue	Y	No Issue

	Spindle Moulder	Overhead Router	Table Router	Weeke CNC	Rye CNC
Machine suitable for Process	Yes	Yes	Yes	Yes	Yes
Expected Set-up time	00:13:26	00:09:30	00:08:25	00:03:12	00:11:03
Expected Unit Processing time	00:01:05	00:01:11	00:01:06	00:01:20	00:01:36
Estimated Processing time	00:10:50	00:11:50	00:11:00	00:13:20	00:16:00
Total Estimated	00:24:16	00:21:20	00:19:25	00:16:32	00:27:03
				Recommend Option	

Yes/No: Yes means that when influenced by the part descriptor or extra information, the part can still be processed on that machine. No means it cannot be processed on that machine and eliminates it as an option.

TABLE 5.2 PROCESS PLANNING GUIDELINES FOR STOPPED GROOVE

Product Name	Jewellery Box	Part	Long Side	Process Description	Stopped Groove
		Qty	10		

		Processing Options									
		Spindle Moulder		Overhead Router		Table Router		Weeke CNC		Rye CNC	
Parameters:	Part Descriptors	Yes/No	Guidelines	Yes/No	Guidelines	Yes/No	Guidelines	Yes/No	Guidelines	Yes/No	Guidelines
Part Shape	Linear	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Size	Very Small - less than 300mm	Y	Requires a work holding Jig to be fabricated	Y	No Issue	Y	Needs end stops fixed to the fence	Y	Requires both sides to be prepared as one for holding	Y	Requires a work holding Jig to be fabricated
Weight	Light - 1kg - 2kg	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Handling capability	Capable of being handled with pushsticks	N	Piece not suitable for drop on cut	Y	No Issue	Y	No Issue	Y	No Issue	Y	Workholding jig incorporates handling safety
Quantity required / Batch size	6 to 10	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Material	Solid Hardwood	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Tooling	5mm Grooving cutter	N	Only large diameter available. Will not create groove	Y	5mm router cutter available	Y	5mm router cutter available	Y	5mm router cutter available	Y	5mm router cutter available
Precision required	Exact to specification	Y	No issue if set-up correctly	Y	No issue if set-up correctly	Y	No issue if set-up correctly	Y	No Issue	Y	No Issue

	Spindle Moulder	Overhead Router	Table Router	Weeke CNC	Rye CNC
Machine suitable for Process	No	Yes	Yes	Yes	Yes
Expected Set-up time	00:00:00	00:02:44	00:07:50	00:06:23	00:11:03
Expected Unit Processing time	00:00:00	00:01:15	00:00:49	00:00:20	00:00:20
Estimated Processing time	00:00:00	00:12:30	00:08:10	00:03:20	00:03:20
Total Estimated	00:00:00	00:15:14	00:16:00	00:09:43	00:14:23
				Recommend Option	

Yes/No: Yes means that when influenced by the part descriptor or extra information, the part can still be processed on that machine. No means it cannot be processed on that machine and eliminates it as an option.

TABLE 5.3 PROCESS PLANNING GUIDELINES FOR THROUGH GROOVE

Product Name	Jewellery Box

Part	Short Side
Qty	10

Process Description	Through Groove

		Processing Options									
		Spindle Moulder		Overhead Router		Table Router		Weeke CNC		Rye CNC	
Parameters:	Part Descriptors	Yes/ No	Guidelines	Yes/ No	Guidelines	Yes/ No	Guidelines	Yes/ No	Guidelines	Yes/ No	Guidelines
Part Shape	Linear	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Size	Very Small - less than 300mm	Y	Requires a work holding Jig to be fabricated	Y	No Issue	Y	No Issue	Y	Requires both sides to be prepared as one for holding	N	Impractable to make jig for such a small component
Weight	Light - 1kg - 2kg	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Handling capability	Unsafe to handle - Workholding jig required	Y	No Issue	Y	Must be fed with a pushstick	Y	Must be fed with a pushstick	Y	No Issue	N	Not suitable
Quantity required / Batch size	6 to 10	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Material	Solid Hardwood	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Tooling	5mm Grooving cutter	Y	5mm grooving cutter available	Y	5mm router cutter available	Y	5mm router cutter available	Y	5mm router cutter available	Y	5mm router cutter available
Precision required	Exact to specification	Y	No issue if set-up correctly	Y	No issue if set-up correctly	Y	No issue if set-up correctly	Y	No Issue	Y	No Issue

	Spindle Moulder	Overhead Router	Table Router	Weeke CNC	Rye CNC
Machine suitable for Process	Yes	Yes	Yes	Yes	No
Expected Set-up time	00:06:48	00:02:44	00:07:50	00:02:52	00:00:00
Expected Unit Processing time	00:00:22	00:00:58	00:00:25	00:01:40	00:00:00
Estimated Processing time	00:03:40	00:09:40	00:04:10	00:16:40	00:00:00
Total Estimated	00:10:28	00:12:24	00:12:00	00:19:32	00:00:00
	Recommend Option				

Yes/No: Yes means that when influenced by the part descriptor or extra information, the part can still be processed on that machine. No means it cannot be processed on that machine and eliminates it as an option.

TABLE 5.4 PROCESS PLANNING GUIDELINES FOR REBATE ON LID

Product Name	Jewellery Box	Part	Lid
		Qty	10
Process Description	Rebate		

		Processing Options									
		Spindle Moulder		Overhead Router		Table Router		Weeke CNC		Rye CNC	
Parameters:	Part Descriptors	Yes/ No	Guidelines	Yes/ No	Guidelines	Yes/ No	Guidelines	Yes/ No	Guidelines	Yes/ No	Guidelines
Part Shape	Linear	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Size	Very Small - less than 300mm	Y	No Issue	Y	No Issue	Y	Needs end stops fixed to the fence	Y	Requires both sides to be prepared as one for holding	Y	Requires a work holding Jig to be fabricated
Weight	Light - 1kg - 2kg	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Handling capability	Capable of being handled with pushsticks	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Quantity required / Batch size	6 to 10	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Material	Solid Hardwood	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Tooling	Rebating Cutter	Y	No Issue	Y	Large diameter cutter	Y	Large diameter cutter	Y	Appropriate cutter	Y	Appropriate cutter
Precision required	Exact to specification	Y	No issue if set-up correctly	Y	No issue if set-up correctly	Y	No issue if set-up correctly	Y	No Issue	Y	No Issue

	Spindle Moulder	Overhead Router	Table Router	Weeke CNC	Rye CNC
Machine suitable for Process	Yes	Yes	Yes	Yes	Yes
Expected Set-up time	00:07:35	00:02:44	00:04:54	00:01:26	00:15:13
Expected Unit Processing time	00:00:39	00:00:49	00:00:33	00:01:36	00:01:45
Estimated Processing time	00:06:30	00:08:10	00:05:30	00:16:00	00:17:30
Total Estimated	00:14:05	00:10:54	00:10:24	00:17:26	00:32:43
			Recommend Option		

Yes/No: Yes means that when influenced by the part descriptor or extra information, the part can still be processed on that machine. No means it cannot be processed on that machine and eliminates it as an option.

TABLE 5.5 PROCESS PLANING SUGGESTIONS FOR JEWELLERY BOX

Product Name	Jewellery Box

Part	All

Process Plan Summary by Component

	Processing Options				
Batch Size: 10 units	**Spindle Moulder**	**Overhead Router**	**Table Router**	**Weeke CNC**	**Rye CNC**
Process: Housing					
Approx. Set-up time	00:13:26	00:09:30	00:08:25	00:03:12	00:11:03
Approx. Processing time	00:10:50	00:11:50	00:11:00	00:13:20	00:16:00
Total Estimated Time	00:24:16	00:21:20	00:19:25	00:16:32	00:27:03
Recommended Process				Weeke CNC	
Process: Stopped Groove					
Approx. Set-up time		00:02:44	00:07:50	00:06:23	00:11:03
Approx. Processing time		00:12:30	00:08:10	00:03:20	00:03:20
Total Estimated Time	N/A	00:15:14	00:16:00	00:09:43	00:14:23
Recommended Process				Weeke CNC	
Process: Through Groove					
Approx. Set-up time	00:06:48	00:02:44	00:07:50	00:02:52	
Approx. Processing time	00:03:40	00:09:40	00:04:10	00:16:40	
Total Estimated Time	00:10:28	00:12:24	00:12:00	00:19:32	N/A
Recommended Process	Spindle Moulder				
Process: Rebate on Lid					
Approx. Set-up time	00:07:35	00:02:44	00:04:54	00:01:26	00:15:13
Approx. Processing time	00:06:30	00:08:10	00:05:30	00:16:00	00:17:30
Total Estimated Time	00:14:05	00:10:54	00:10:24	00:17:26	00:32:43
Recommended Process			Table Router		

Time taken to complete batch using recommended processes

Process	Processing Option Chosen	Time Taken
Housing	Weeke CNC	00:16:32
Stopped Groove	Weeke CNC	00:09:43
Through Groove	Spindle Moulder	00:10:28
Rebate on Lid	Table Router	00:10:24

Total Processing Time	00:47:07

As already mentioned the spreadsheet solution has returned a process plan with a 14% more efficient route than was produced by the eight highly experienced technical people who generated process plans for the jewellery box which gives credibility to the system.

To demonstrate further the ability of the spreadsheets another example is shown. A dummy product, components of a small drawer, are input into the spreadsheet and the results are shown. The drawer has 5 components, the drawer front, the drawer sides, the back and the base, see figure 5.4 and 5.5. The drawer front has a stopped groove and a housing. The drawer sides and back have a through groove. The base is simply cut square to size and no further processing is required. The batch quantity for this example is 15 drawers.

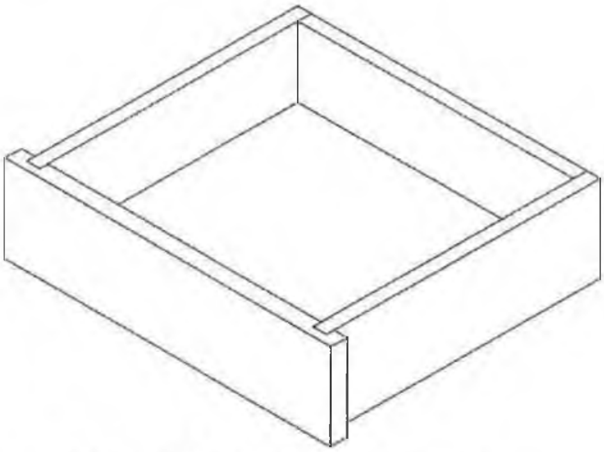

FIGURE 5.4 ASSEMBLED DRAWER.

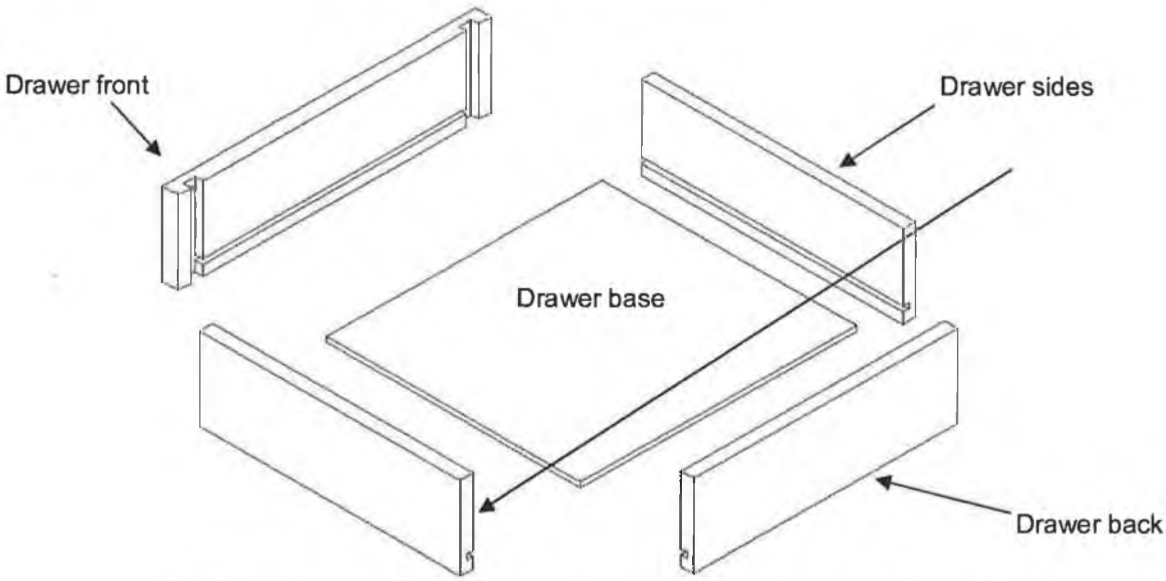

FIGURE 5.5 EXPLODED VIEW OF DRAWER COMPONENTS.

As the drawer sides and back have the same processes carried out and are almost identical in size, they will be treated as the same type of component for this example. There are two sides and one back per drawer, a total of 45 components for the batch of 15 drawers. A total of 15 drawer fronts are required.

TABLE 5.6 PROCESS PLANING GUIDELINES FOR THROUGH GROOVE ON DRAWER.

Product Name	Small Drawer	Part	Drawer Side	Process Description	Through Groove
		Qty	45		

		Processing Options									
		Spindle Moulder		Overhead Router		Table Router		Weeke CNC		Rye CNC	
Parameters:	Part Descriptors	Yes/ No	Guidelines	Yes/ No	Guidelines	Yes/ No	Guidelines	Yes/ No	Guidelines	Yes/ No	Guidelines
Part Shape	Linear	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Size	Very Small - less than 300mm	Y	Requires a work holding Jig to be fabricated	Y	No Issue	Y	No Issue	Y	Requires both sides to be prepared as one for holding	N	Impractable to make jig for such a small component
Weight	Light - 1kg - 2kg	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Handling capability	Unsafe to handle Workholding jig required	Y	No Issue	Y	Must be fed with a pushstick	Y	Must be fed with a pushstick	Y	No Issue	N	Not suitable
Quantity required / Batch size	6 to 10	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Material	Solid Hardwood	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Tooling	5mm Grooving cutter	Y	5mm grooving cutter available	Y	5mm router cutter available	Y	5mm router cutter available	Y	5mm router cutter available	Y	5mm router cutter available
Precision required	Exact to specification	Y	No issue if set-up correctly	Y	No issue if set-up correctly	Y	No issue if set-up correctly	Y	No Issue	Y	No Issue

	Spindle Moulder	Overhead Router	Table Router	Weeke CNC	Rye CNC
Machine suitable for Process	Yes	Yes	Yes	Yes	No
Expected Set-up time	00:06:48	00:02:44	00:07:50	00:02:52	00:00:00
Expected Unit Processing time	00:00:22	00:00:58	00:00:25	00:01:40	00:00:00
Estimated Processing time	00:16:30	00:43:30	00:18:45	01:15:00	00:00:00
Total Estimated	00:23:18	00:46:14	00:26:35	01:17:52	00:00:00
	Recommend Option				

Yes/No: Yes means that when influenced by the part descriptor or extra information, the part can still be processed on that machine. No means it cannot be processed on that machine and eliminates it as an option

Table 5.6 above shows the total estimated time for producing the drawer sides and back. The spindle moulder is the recommended machine for the process with a time of 23 minutes and 18 seconds. Interesting to note that the Weeke CNC has the worst outcome for the larger batch size of 45 components, at one hour 17 minutes and 52 seconds which tends to verify findings from earlier examples that the CNC is more suitable to small batch sizes.

Table 5.7 shows the total estimated time for producing the stopped groove on the drawer fronts. The Weeke CNC is the machine of choice this time at 11 minutes and 23 seconds, again interesting to note that when the batch size is reduced to 15, the Weeke has the most favourable results.

TABLE 5.7 PROCESS PLANING GUIDELINES FOR STOPPED GROOVE ON DRAWER FRONTS.

Product Name	Small Drawer	Part	Drawer Front	Process Description	Stopped Groove
		Qty	15		

		Processing Options									
		Spindle Moulder		Overhead Router		Table Router		Weeke CNC		Rye CNC	
Parameters:	Part Descriptors	Yes/No	Guidelines	Yes/No	Guidelines	Yes/No	Guidelines	Yes/No	Guidelines	Yes/No	Guidelines
Part Shape	Linear	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Size	Very Small - less than 300mm	Y	Requires a work holding Jig to be fabricated	Y	No Issue	Y	Needs end stops fixed to the fence	Y	Requires both sides to be prepared as one for holding	Y	Requires a work holding Jig to be fabricated
Weight	Light - 1kg - 2kg	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Handling capability	Capable of being handled with pushsticks	N	Piece not suitable for drop on cut	Y	No Issue	Y	No Issue	Y	No Issue	Y	Workholding jig incorporates handling safety
Quanity required / Batch size	5 to 10	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Material	Solid Hardwood	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Tooling	5mm Grooving cutter	N	Only large diameter available. Will not	Y	5mm router cutter available	Y	5mm router cutter available	Y	5mm router cutter available	Y	5mm router cutter available
Precision required	Exact to specification	Y	No issue if set-up correctly	Y	No issue if set-up correctly	Y	No issue if set-up correctly	Y	No Issue	Y	No Issue

	Spindle Moulder	Overhead Router	Table Router	Weeke CNC	Rye CNC
Machine suitable for Process	No	Yes	Yes	Yes	Yes
Expected Set-up time	00:00:00	00:02:44	00:07:50	00:06:23	00:11:03
Expected Unit Processing time	00:00:00	00:01:15	00:00:49	00:00:20	00:00:20
Estimated Processing time	00:00:00	00:18:45	00:12:15	00:05:00	00:05:00
Total Estimated	00:00:00	00:21:29	00:20:05	00:11:23	00:16:03
				Recommend Option	

Yes/No: Yes means that when influenced by the part descriptor or extra information, the part can still be processed on that machine. No means it cannot be processed on that machine and eliminates it as an option.

TABLE 5.8 PROCESS PLANING GUIDELINES FOR HOUSING ON DRAWER FRONTS.

Product Name	Small Drawer	Part	Drawer Front	Process Description	Housing
		Qty	15		

		Processing Options									
		Spindle Moulder		Overhead Router		Table Router		Weeke CNC		Rye CNC	
Parameters:	Part Descriptors	Yes/No	Guidelines	Yes/No	Guidelines	Yes/No	Guidelines	Yes/No	Guidelines	Yes/No	Guidelines
Part Shape	Linear	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Size	Very Small - less than 300mm	Y	Requires a work holding Jig to be fabricated	Y	No Issue	Y	Needs a backing board to stop breakout	Y	Requires both sides to be prepared as one for holding	Y	Needs a backing board to stop breakout
Weight	Light - 1kg - 2kg	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Handling capability	Capable of being handled with pushsticks	Y	Workholding jig incorporates handling safety	Y	Backing board aids safe handling	Y	Backing board aids safe handling	Y	No Issue	Y	No Issue
Quantity required / Batch size	5 to 10	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Material	Solid Hardwood	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue	Y	No Issue
Tooling	12mm cutting tool required except for the CNC's	Y	Tooling Available	Y	Tooling Available	Y	Tooling Available	Y	Tooling Available	Y	Tooling Available
Precision required	Exact to specification	Y	No issue if set-up correctly	Y	No issue if set-up correctly	Y	No issue if set-up correctly	Y	No Issue	Y	No Issue

	Spindle Moulder	Overhead Router	Table Router	Weeke CNC	Rye CNC
Machine suitable for Process	Yes	Yes	Yes	Yes	Yes
Expected Set-up time	00:13:26	00:09:30	00:08:25	00:03:12	00:11:03
Expected Unit Processing time	00:01:05	00:01:11	00:01:06	00:01:20	00:01:36
Estimated Processing time	00:16:15	00:17:45	00:16:30	00:20:00	00:24:00
Total Estimated	00:29:41	00:27:15	00:24:55	00:23:12	00:35:03
				Recommend Option	

Yes/No: Yes means that when influenced by the part descriptor or extra information, the part can still be processed on that machine. No means it cannot be processed on that machine and eliminates it as an option.

Table 5.8 shows the total estimated time for producing the housing on the drawer fronts. The Weeke CNC is the recommended machine at 23 minutes and 12 seconds.

TABLE 5.9 PROCESS PLANING SUGGESTIONS FOR DRAWER.

Product Name: Drawer | Part: All | Process Plan Summary by Component

Batch Size: 15 units

	Processing Options				
	Spindle Moulder	Overhead Router	Table Router	Weeke CNC	Rye CNC
Process: Housing					
Approx. Set-up time	00:13:26	00:09:30	00:08:25	00:03:12	00:11:03
Approx. Processing time	00:16:15	00:17:45	00:16:30	00:20:00	00:24:00
Total Estimated Time	00:29:41	00:27:15	00:24:55	00:23:12	00:35:03
Recommended Process				Weeke CNC	
Process: Stopped Groove					
Approx. Set-up time		00:02:44	00:07:50	00:06:23	00:11:03
Approx. Processing time		00:18:45	00:12:15	00:05:00	00:05:00
Total Estimated Time	N/A	00:21:29	00:20:05	00:11:23	00:16:03
Recommended Process				Weeke CNC	
Process: Through Groove					
Approx. Set-up time	00:06:48	00:02:44	00:07:50	00:02:52	
Approx. Processing time	00:05:30	00:14:30	00:06:15	00:25:00	
Total Estimated Time	00:12:18	00:17:14	00:14:05	00:27:52	N/A
Recommended Process	Spindle Moulder				

Time taken to complete batch using recommended processes

Process	Processing Option Chosen	Time Taken
Housing	Weeke CNC	00:23:12
Stopped Groove	Weeke CNC	00:11:23
Through Groove	Spindle Moulder	00:12:18
Total Processing Time		00:46:53

The process planning suggestions for manufacturing the drawer components are shown in table 5.9 above. This further example has served to show that the process planning spreadsheet can be used to generate process planning options for other products with similar processing characteristics.

However, this is only an example. An actual expert system would have many different types of process descriptions and not just those shown in the examples above. Processes such as morticing, tenoning, dowelling, edging, veneering, sanding, finishing, and many more would need to be included along with recorded times, to have the system useful.

5.3 Process Planning Guidelines – Feedback

To analyse the relevance of the PP guidelines, if any, the results of the process planning trials and the guidelines were shown to each of the eight process planners. As mentioned earlier, these are all very skilled and experienced in the manufacture of furniture and wood products. They were shown copies of their original process plans for comparison. The process planners were interviewed individually as opposed to a focus group. To gather relevant and focused information the following questions were put to each process planner:

(a) What is your reaction to viewing the results of the trials?

(b) Based on the information presented in the process planning guidelines would this information cause you to change your process plans?

(c) If you had an extensive knowledge base with this kind of information relating to woodworking processes would you find it valuable and would you use it to process plan in the future?

(d) Why do you think you did not consider the other processing options in the first place?

Feedback from Question A

(a) What is your reaction to viewing the results of the trials?

The results obtained in the trials by some planners were better than others and their reactions mirrored this. Most people reacted with an element of surprise and intrigue. The author observed a general feeling of frustration that the process planners had not been going through this thought process when designing and producing furniture products in the past. One person commented that process planning should be an integral part of product design education and that he was previously unaware of its significance.

Some of the planners questioned the validity of the trials exclaiming that there could not be such variation between the different machines. However, after going through the results in more detail they were satisfied they were valid.

Feedback from Question B

(b) Based on the information presented in the process planning guidelines would this information cause you to change your process plans?

In answering this question, naturally the planners whose plans performed well choose to remain with their existing route. Some did comment that they would think a bit more about it before making a final decision.

In the trials where the Weeke CNC performed best, the planners who are not fully trained on the machine said they still had no option to use that process.

The process planner using the Rye CNC proclaimed disgust at the results. They genuinely questioned how it could be so far off the other processes. They commented they certainly would use different processes based on the guidelines.

Certain people made excuses. They felt their method should have been better. They said that when originally asked to participate in the process planning, they were very busy and they did not give it enough thought. This raised a very interesting thought. Surely the same is true in a company situation. People making process planning decisions are generally very busy people. Therefore it is reasonable to assume that when they are deciding how products or components are made, i.e. process planning, they simply don't have enough time to analyse their options. They possibly 'jump' to the first decision they think of.

Feedback from Question C

(c) If you had an extensive knowledge base with this kind of information relating to woodworking processes would you find it valuable and would you use it to process plan in the future?

There was a mixed reaction to this question. Most of the planners initially replied yes. However, as discussion progressed some questioned the possibility of such a system ever existing, due to the almost infinite possible variations of parts and processes. The author pointed out that there is a limited amount of processes, albeit very many, and that it was design, shape, material, scale, etc. that was infinite. While some of the planners accepted this, there were still some in doubt.

Others commented that the time difference between some of the processes was only minutes and that such a system would need to be almost instant to warrant using it. On the other hand, one commented that if it was for a product which was to be produced regularly, that it certainly would have benefits in the long run.

Feedback from Question D

(d) Why do you think you did not consider the other processing options in the first place?

Again there was a mixed reaction to this question. A few planners commented that they thought their choice was the easiest way to produce the products and didn't really consider the speed of production to be an issue.

When prompted if they used their chosen processes regularly, most agreed that they did. Again this could indicate a preference to the processes that are most familiar to the planner.

Some said that it simply was the first thought that came into their mind upon looking at the working drawings and they did not look beyond after that.

5.4 Process Planning Methodology

Ciurana et al, (2003) concluded that "*The traditional approach to resolving the process planning task is the one found in a manufacturing company, when the plans are handed over to the manufacturing process experts who then specify the procedures to make the product. The process planners, using their experience and knowledge, generate instructions for the manufacture of the products based on the design specifications and the available installations and operators. The fact that there are few experienced process planners and that, when faced with the same problem, different process planners would probably come up with different plans is an indication of the heterogeneity that exists in process planning. But, in short, consistent and correct planning requires two things: knowledge of manufacturing processes and experience.*" (Ciurana et al, 2003).

It is interesting that Ciurana et al's (2003) conclusion about consistency and correct planning did not hold in these process planning trials. The people chosen to create the plans were very well qualified and experienced users of furniture and wood products manufacturing processes. So what happened? Why had they such different process plans? Well, based on their response to the guidelines developed after the trials, it seems that process planning is almost a subconscious activity for many people; where many processing options have been de-emphasised by the individual because they favour other particular processes.

It was noted already that there are no known 'process planning' positions in the furniture and wood products industry in Ireland, but there are a lot of highly experienced supervisors, machinists, and more recently a lot of highly qualified, but maybe not experienced, CAD technicians/product engineers. So, it appears that a knowledge base of process specific guidelines would have benefits both for the experienced people, by highlighting options they have dismissed in the past, and for inexperienced product engineers struggling to figure out how to detail design products and the processing implications of their decisions.

Kamrani and Vijayan (2006) investigate the use of manufacturing templates (essentially outline process plans) in an integrated approach to product and process development. They used these process templates in a tool developed to reduce cost by foreseeing manufacturability constraints during concept generation. They also claim, by using templates, the time required for new product development is drastically reduced and that "*At the same time incorporating computer-aided process planning into the system gives the designer a better understanding of the cost implications of the modified design with respect to manufacturing*."

The provision of alternative process plans and feedback on their performance through a knowledge base is a key output of this thesis. Such information reminds the experienced planner of the alternatives and provides valid options to the inexperienced planner. It also provides designers and engineers with a response about the effects of design choices on processing performance. This is something that is valuable at earlier stages of the design to manufacture cycle. This was a key observation of the planners in the process trials after the results and the process guidelines were communicated back to them. Based on this conclusion a methodology for introducing process planning questions and intelligence into the earlier stages of the design to manufacture cycle is proposed.

The 'Total Design' methodology developed by Stuart Pugh (1991) identified the five stages in the design to manufacture cycle. Decisions are made at each stage. Formal DFM analysis is conducted at the detail design stage, allowing for process plans to be created. However, based on findings throughout this research, the author feels that process planning decisions are being made, consciously or unconsciously, at each stage. Figure 5.6 outlines the stages in the design to manufacture cycle and identifies specific drivers that may cause process planning decisions to be made at each stage. Following that, relevant actions at each stage are identified.

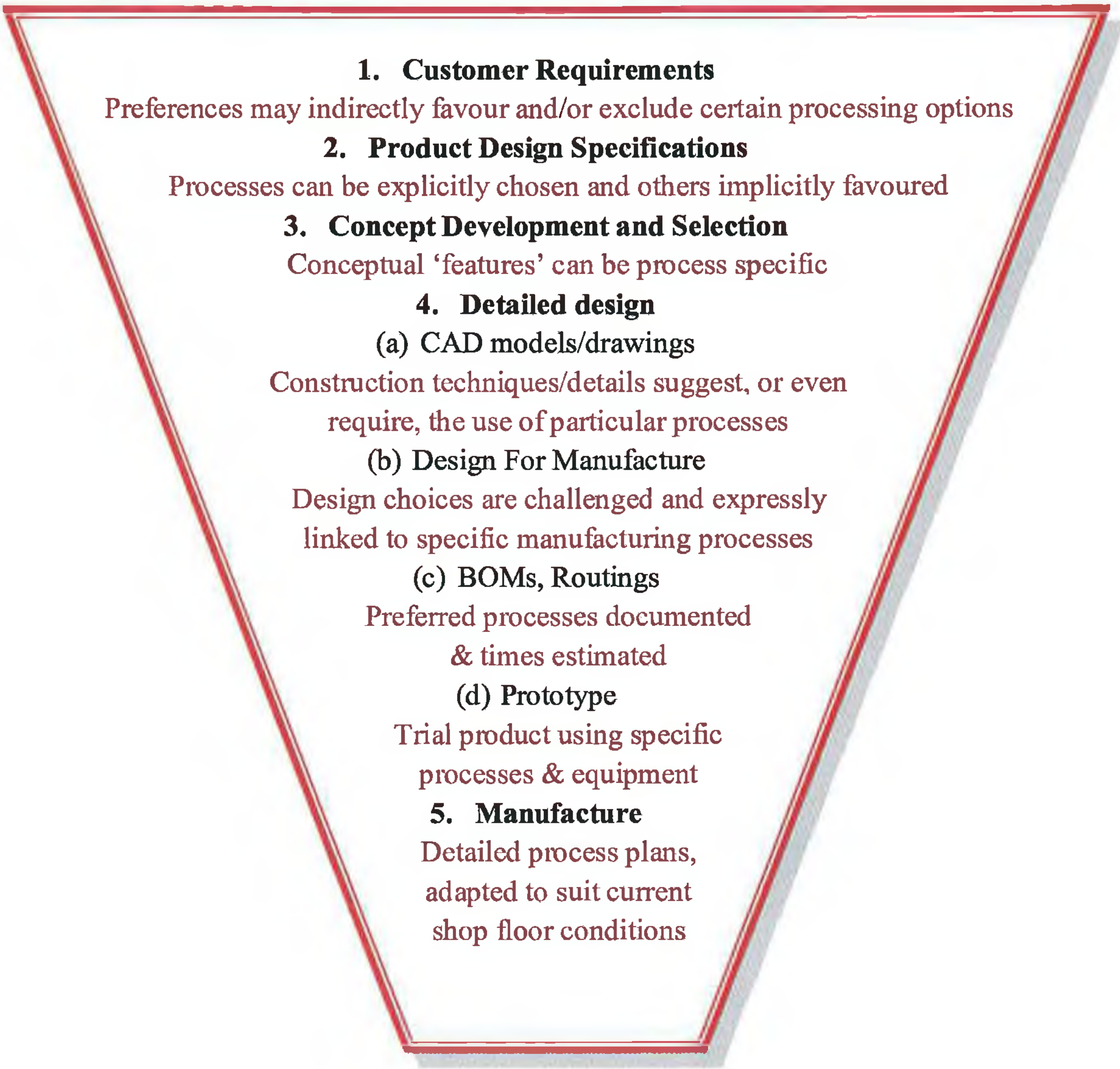

FIGURE 5.6 – PROCESS DECISION-MAKING (ADAPTED FROM PUGH, 1991)

Once the Design-to-Manufacture cycle begins, design decisions are being made (directly or indirectly) at each stage. With each design choice manufacturing process options are being either chosen, favoured, or even excluded, implicitly or explicitly. The following actions are relevant at each stage of the cycle.

1. Customer - If a customer requires a particular material, that material might be more suited to certain processes and equipment. If they specify particular sizes that constrain part size and shape, then that may exclude the use of certain machines. *Action - the designer should document any process implications associated with the customer's requirements.*

2. PDS - Certain questions in the construction of a PDS are directly related to the processing requirements for the product and the processing capability of the manufacturing facility. Other questions like size and shape indirectly constrain processing options. *Action – Identify process choices, decisions or implications.*

3. Concept - If the design includes features such as raised and fielded panels, or particular styles of moulding, or curved panels, this will suggest particular processes and will exclude others. *Action – Document the processing repercussions of conceptual design.*

4. Detail
    a. CAD models – The engineer will have to figure out how to construct the product in order to fulfil the designer's vision. In some cases they might even be the same person. In any event, when the construction detail is applied to the product, process decisions are being made. *Action – List explicit process decisions resulting from construction detail.*

    b. DFM – As discussed, DFM is rarely practiced formally. However, informally, there may be changes made to the design based on feedback from someone in production, or a senior engineer, or others regarding the manufacturability of the product and parts. This feedback will cause design changes to suit processing capability, i.e. specific processes. *Action – Document DFM changes to the design and the favoured processes.*

c. BOMs, Routings – The Process Routing is closely linked to the Bill of Materials, and in many cases is regarded as a preferred process plan. However, in reality many FWP companies do not create BOM's or routings. Instead they create cutting lists. So when the materials/parts hit the production floor, the informal process planning is carried out by a supervisor or machinist based on their preferences and current availability of resources. *Action – Create Process Routings based on the process planning guidelines and reference alternatives in the knowledge base.*

d. Prototype – The production of a prototype often yields design changes with possible changes in processing choices. *Action – Document design changes and processing implications.*

5. Manufacture – At this stage the product goes to production and the preferred processing options may or may not be available, or they may not make sense considering the current mix of products and production quantities. The planner should use the guidelines in the knowledge base to select the best process plan. *Action – Detail the final chosen process plan.*

Summary of Process Planning Methodology Action Points

1. Document any process implications associated with the customer's requirements.
2. Identify process choices, decisions or implications from the PDS
3. Document the processing repercussions of conceptual design.
4.
    a. List explicit process decisions resulting from construction detail in CAD Models
    b. Document DFM changes and the processes driving the changes.
    c. Create Process Routings based on the process planning guidelines and reference alternatives in the knowledge base.
    d. Document prototype design changes and processing implications.
5. Detail the final chosen process plan.

Based on the application of the above steps, with the support of a knowledge base containing process planning guidelines at each stage, the author believes this would greatly improve consistency and performance in the design to manufacture cycle in the furniture and wood products industry.

The diagram shown in figure 5.7 over illustrates the proposed integration between the process planning guidelines and the process decision making that takes places throughout the design to manufacture cycle. It also highlights this integration as being at the core of the outlined process planning methodology.

FIGURE 5.7 PROCESS PLANNING METHODOLOGY DIAGRAM

The application of process planning thinking and discipline at the other stages is a new concept. Care would have to be taken that the earlier stages were not overwhelmed with detail. The information would need to be 'presented' in the appropriate level of detail at each stage.

Tsai et al (2010) developed a process planning and design system, using knowledge based techniques, for complex freeform automotive parts. They combined case-based reasoning with ordinary process planning and design methods, and classified it as a hybrid expert system. The system can adapt existing designs or generate new designs based on the processing knowledge.

Research by Yim & Rosen (2007) found that the process planning task for a given design problem in additive manufacturing can be greatly enhanced by referencing previously developed process plans. "*In this research, a case-based retrieval method, called the DFM (Design For Manufacturing) framework, that retrieves previously formulated process plans is proposed to support process planning.*" They developed an information model of manufacturing process knowledge including design requirements, process plans, and rules that map requirements to plans. They also developed storage and retrieval algorithms that, structured the repository of previous DFM problems and, enable DFM problems to be retrieved.

5.5 Conclusions

This chapter showed the creation of process planning guidelines. The system is spreadsheet based and uses the principles of a case-based expert system as discussed by Humm et al (1991), Tsai et al (2010). It was decided to focus the guidelines on one of the products used for the process trials as a first step in populating a knowledge base as a process planning system. The intention is that as more cases are added to the knowledge base, the more accurate the results returned will be.

The process planning guidelines were developed to focus on the process required for a component to become closer to completion, for example, creating a housing, a rebate, a mortise, etc. It was more logical to identify which machines can perform the required process, as opposed to identifying the almost infinite possible processes each machine can be adapted to perform.

The results of process planning trials along with the process planning guidelines were demonstrated to the eight original process planners involved in the trials, and feedback was gathered in the form of structured questioning. This gave a valuable insight into how process planning is approached. The feedback indicated that the suspicions of user preferences in relation to process planning decisions were real. It also highlighted that process planning decisions are being generated by very busy people which might restrict them from having the time to analyse other processing options.

This led towards the development of a process planning methodology which was further integrated with the stages involved in the design to manufacture cycle.

6. Conclusions and Recommendations

6.1 Introduction

This chapter draws the main conclusions of this research and is followed by the identification of a number of areas for further research. Outline specifications for a process planning decision support system are identified and the integration of a process planning methodology into a DFM framework is suggested.

6.2 Conclusions

There is little research available in the areas of DFM or Process Planning in the Irish FWP industry, and probably very little effort has been made to take advantage of these techniques, particularly in the type of small to medium sized enterprises that dominates the Irish FWP manufacturing industry. This suggests potential for these techniques in this industry.

The general research into the design-to-manufacture cycle, DFM and particularly process planning and CAPP suggested that process decisions or choices are made, consciously or unconsciously, at almost every step of the design to manufacture cycle. This is significant because the proliferation of CAD/CAM systems in the furniture and wood products industry has shifted many construction decisions and consequently process decisions away from the experienced people in manufacturing and puts them in the hands of design engineers. This suggests that the 'positioning' of process planning after design and before manufacture is too restrictive. Thus, there is potential to use process planning techniques to assist with DFM earlier in the design cycle.

The author was particularly interested in DFM and process planning for CNC production. CNC's are not just a straight substitute for traditional processes. The cases studies showed that there are significant opportunities to improve performance if the designers and planners fully understand, and have experience of, the technology and redesign products to suit. The technology is particularly suited for small batch runs and achieves fast set-up times. However, there are indications that companies focused on solid wood processing may have more difficulty redesigning products for CNC than companies with panel processing capability and experience. The process trials confirmed CNC to be very flexible for fast set-up times and performed well against traditional machines for small batch quantities. However, it was found that they are not the answer to all manufacturing problems as the traditional machinery performed better for larger batch quantities.

No evidence of any formal process planning activities was uncovered in the secondary or primary research. Evidence of informal process planning was revealed. It emerged that processing decisions were being made informally, but with no real consideration for time or cost advantage, or for alternative processing options. The decisions were being based on people's personal preferences for using a particular process which had a high degree of familiarity to them. Process planning trials were conducted using process plans prepared by eight skilled and experienced technical staff. It revealed disparity between processes chosen by different planners and created justification for the development of a process planning guidelines.

The provision of process planning guidelines to suggest alternative process plans through a knowledge base is a key output of this thesis. The process planning guidelines were developed and applied to a sample exercise to demonstrate the functionality of the technique. The development of a comprehensive knowledge base of guidelines is required to cover the wide variety of processes in the FWP industry. The feedback, from the trial planners, regarding these guidelines was positive and included observations that the guidelines would be useful earlier in the design process. These observations supported the theory (formulated earlier) that process planning decisions were being effected at other stages of the design-to-manufacture cycle.

The process planning guidelines were integrated into a larger process planning methodology. This methodology provides process planning support to all stages involved in the design to manufacture cycle, and promotes overall DFM and manufacturing process awareness. The process planning methodology described in this thesis represents a starting point for the consideration of a more all encompassing DFM framework. Recommendations regarding this and other opportunities are outlined below.

The implementation of the methodology supported by the knowledge base will be a valuable tool for FWP companies in the development of products in the future. It has the potential to be a practical, relevant and integral part of the design-to-manufacture cycle particularly for the type of flexible SME's in the Irish FWP industry.

6.3 Recommendations

The author recommends the use of process planning techniques in the furniture and wood products industry. It is clear from the research that there are benefits to be gained from the application of the guidelines at a number of stages in the design-to-manufacture cycle. The tool and methodology proposed are simply a starting point and the following areas are suggested for further research:

- In order to develop and grow the knowledge base, many more cases and results must be collected and the associated process planning guidelines developed for inclusion in the knowledge base. This should be done over time as discussed in Humm et al (1991).
- All of the attention in the trials was focussed on CNC machining and a small selection of alternative process options. Much more work could be done on the development of trials and tests focused on other equipment, for example 5-axis CNC machines and nesting CNCs.
- Some investigation into the dangers of presenting too many alternatives is required. Usher (2003) claims that the advantage gained by increasing the number of alternative process plans diminishes rapidly. In fact, he claims that under some conditions for the particular system he studied, increasing the number of

alternatives actually resulted in degraded system performance. "*Based on these results developers of process planning systems and methodologies need to evaluate carefully the benefit of expending time and resources on the generation of alternative plans or optimal plans*" (Usher, 2003). However Sormaz and Khoshnevis (2003) claim that "*the availability of alternative process plans is a key factor for integration of design, process planning, and scheduling functions*."

- The effect of lecturer biases influencing students and graduates process preferences would be another interesting topic for future research. It's more important perhaps than the similar effect on say apprentices in a workshop environment, because (based on anecdotal experience) the 3rd level graduates tend to find themselves moving from one company to another a lot more than apprentices would. Therefore they need a more open mind and need to embrace a lot more options. They will also find themselves in the position of designer or engineer with much more influence over the way products are processed than perhaps the traditional machinist or supervisor.
- The initial investment required by a company to purchase a CNC machining centre can be considerable depending on the type and capability of the machine acquired. If the CNC is capable of producing products at a marginally faster rate than using traditional machines, then one could argue whether the investment is worth it? The Weeke CNC in the machine workshop in GMIT Letterfrack has a purchase value of €110,000 when new. A professional quality spindle moulder, overhead router and hand router could all be purchased for a total of less than €15,000. Thus offering a more economical, traditional solution for far less capital investment. However, based on experience and the colleges industrial links most companies who purchase a CNC machine will already have the traditional machines for many years previous to making a commitment to purchase a CNC machining centre. Therefore, at the time of considering when to invest in CNC technology, no capital investment is required to continue production in the traditional manner. It is possible, that it may be more prudent to continue to produce the products, even if marginally slower and incurring a slightly higher labour cost, with the traditional processes rather than having the capital overhead

from the CNC purchase. As demonstrated earlier this is design specific as to whether these efficiencies are achieved. An investigation into the capital investment decisions for CNC technology and the associated benefits or drawbacks for furniture and wood products companies should be conducted.

- There is considerable anecdotal evidence that there has been a huge uptake in the acquisition of CNC technology and CAD/CAM systems to operate the technology in recent years in the furniture and wood products industry, an investment in manufacturing equipment. There was no evidence uncovered to suggest that this was complimented by any significant parallel investment into the stages that transpire before a product is manufactured, i.e. product development. Further research as to why one is considered without the other, and the associated implications, could help develop a more streamlined operation for furniture and wood products companies.
- One of the primary motivations for this thesis was the high use of CNC machines in the Irish industry. There is significant opportunity to research the ways in which CNC machines are utilised in the industry and the unexploited potential of the technology in terms of product design and competitive manufacturing.
- The simplification of the range of machines to be documented would be very useful. Xu and Li (2008) developed a clustering /averaging method to partition and classify the machines available on the shop floor. This would reduce the number of machine options in the planning system. This concept could be relevant to woodworking firms. For example, if a furniture company had three slightly different spindle moulders; data from each machine could be classified under the same code, and averaged if appropriate based on the part characteristics.

6.4 List of Functions for a Process Planning Decision Support System

The process planning methodology could be very useful, but if it were combined with the knowledge base (guidelines) in a decision support system it could be much more powerful. A decision support system required to assist the application of the above methodology should be developed based on the following specifications.

- Rule-based expert system

- Driven by a case-based Knowledge Base

- Questions and Decision Trees based on the Process Planning Methodology and Design-to-Manufacture Cycle

- Maintain data on a case by case basis including
    - CAD Model
    - Material type (solid – plus solid variations e.g., ash, deal, hard rock maple, etc. MDF, laminate, and so on.)
    - Material size & weight (component dimensions)
    - Batch size. The CNC may be faster for 5 components but the spindle moulder may be more economical for 100.
    - Jigs required, (generally work holding devices to aid the manufacturing process)
    - Tool speeds. Generally faster tool speeds give a cleaner finish but is also affected by material type.
    - Feed speeds, how fast the tool travels through the material. May cause burn mark if too slow or break out of grain if too fast.

- The system should have data stored for
    - Machine function and ability
    - Tooling available for each machine
    - Tooling available but not in stock
    - Quality of finish achievable
    - Capacity of processes

- Display alternative process plans to the user with associated guidelines

- Rank the plans based on the guidelines and based on time/cost estimates calculated from previous case examples

6.5 DFM Framework

The diagram shown in figure 6.1 repeats (from figure 5.2) the proposed integration between the process planning guidelines and the process decision making, and highlighting of the integration at the core of the outlined process planning methodology. At the highest level (beyond the scope of this thesis) the process planning methodology should be a key component of an overarching DFM framework. This framework should encompass all phases of the design to manufacture cycle. It should not just be a sub-step in any one phase. The full scope of such a framework should be the subject of further research and could involve expanding the application of other techniques, e.g. value analysis, similar to the way the author has applied process planning in this thesis. The application of such a framework would be very appropriate to a concurrent engineering environment.

FIGURE 6.1 - PP METHODOLOGY IN A DFM FRAMEWORK

The DFM framework might include several complimentary methodologies potentially applied throughout the overall design to manufacture cycle, in the same way as process planning is applied in this thesis.

6.6 Final Thought

Based on the outcome of research activities, results found in the process planning trials and feedback from the process planning guidelines, there appears to be sufficient evidence to indicate that there are significant time, capacity and cost benefits to be earned from implementing an effective process planning methodology.

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Appendix 1

Professional Placement - Company Operations Questionnaire

The following questionnaire has been designed as a tool to assist in examining the information gathered, formally and informally, during the co-op placement. As well as formal information gathering, learning often takes place where knowledge about the company is absorbed by being present there and taking part in company operations activities. By working through the questionnaire knowledge of the company can be documented and used in the final report. However, remember that the questionnaire is simply a tool. It is designed to prompt discussion about aspects of the company that may not have been formally examined. It is not necessary to answer every question in detail, and in fact the company may not wish to provide answers to some of the questions.

General Business Situation

Products

- What products / product types does the company sell ?
- What is the percentage breakdown of sales by product or product type ?

Customers

- How many types of customers are there ? Who buys what ?

Sales Orders

- How does the company receive sales orders? How do they distribute their products ?

Quoting & Costing

- How do they generate quotes? How do they cost their products?

Competitors

- Who are their competitors ? Identify the key competitive factors
- How do they compare with their competitors ?

Human Resources

- How many people employed by the company?
- How many in manufacturing, sales, admin etc ?
- What is the organisation structure ?

- Do they use temporary employees, shifts, overtime?

Suppliers

- Who are their suppliers ? How do they perform on quality and delivery?
- Describe their procedures for selecting suppliers ?
- How does the company generate purchae orders

R & D

- Is R&D a relevant part of the business ? How is it managed?

Engineering

- How is engineering managed ?

Computer Hardware

- What hardware, and network, does the company have at present ?
- What is level of hardware expertise in the company ?
- Do they have CNC or other automation. If so, describe?

Computer Software

- What software do they use at present ?
- What is the level of software expertise in the company ?

Production management

- Describe the company's overall production system (Job shop/batch/mass production, flexible/line flow)
- How does the company deal with
    - Sales orders
    - Forecasting
    - Capacity planning
    - Stock control
    - Raw material purchasing, and sub-contractors
    - Tooling
    - Process Planning
    - Production scheduling

  - Production control
  - Works orders
  - Personnel levels
  - Dispatch, shipping, and invoicing
- Describe a typical Bill of Materials BOM ?
- Describe a typical Process Routing ?
- How is data collected from the shopfloor ?

Layout and Material Flow

- What operations are involved in the process ?
- Where are they located (Drawing) ?
- Is the layout product (line flow) or process oriented ?
- How is work-in-process (WIP) controlled ?
- How are rejects controlled ?

Inventory policy & control

- How much finished goods does company typically hold ?
- How much raw material does company typically hold ?
- How much WIP does the company typically hold ?
- What is typical production batch size ?
- How many inventory turns per year ?
- How many different finished products does company have
- How many different raw materials does the company use ?
- Do they use a formal Materials Planning system ?
- Do they use product groups (details & examples) ?
- How do they organise and control their inventory ?

Production Process

- What is the capability, typical function, and availability of each machine ?
- Is there a maintenance programme (describe) ?

- Who is involved in setting up each machine ?
- Is there a cross training programme for Operators ?
- How many employees are multi-skilled ?

Product Design

- Is there a product design function (describe) ?
- Describe the design procedure ?

Performance measurement/improvement

- What aproach has the company taken to performance measurement ?
- What has management done to achieve current performance levels ?
- What does management intend to do to improve performance?
- Are employees rewarded for good performance ?

Office and administration procedures

- Describes the activities of each support department.
- How often does the management team meet ?
- What type of other meetings take place ?

Quality Systems

- Have the company's a formal approach to quality (Describe) ?
- Who has ownership of quality ? Explain.
- Are there any measures of quality costs?
- What are reject and scrap levels ?