University of British Columbia

Economic Analysis of Investment Decisions in Tooling in Operation for Kitchen Cabinet Manufacturers

WOOD 493: Project in Program Major

Moon, Andy

Prepared as an Undergraduate Thesis (WOOD 493) for Patrick Cramond and Taraneh Sowlati at the University of British Columbia's Faculty of Forestry

Submitted in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in Wood Products Processing
April 18, 2011

Executive Summary

- Going into the 21st century, importance of tooling has been realized to show effectiveness in improving the performance in machining operations

- Similar to other machining operations, optimized tooling of CNC router bits has taken an important role in improving the overall performance of CNC machining in terms of cutting quality, machining productivity, and economics in operation

- Variation in physical properties of CNC router bits including the router bit's tool diameter, number of flutes, design and knife arrangements of cutting edge and the resultant cutting angles, as well as the material used to tip the bit's cutting edge all have an impact on the performance of CNC machining

- Operational variations including the feed rate, RPM, and cutting depth also have great impacts on machining parameters

- Smart decisions should be made in choosing and purchasing CNC router bits in consideration to the tool's price to performance ratio

- In cost-benefit analysis, net present value is a very useful indicator to aid in decision of either accepting or rejecting the investment

- The case study in finding a better alternative tooling solution started from proposal to Platinum Millwork to process of information sharing and data collection with Quality Saw & Knife, and finally use of cost-benefit analysis to assess the net benefits of using diamond-tipped router bits in comparison to maintaining the use of Platinum's formal carbide router bits

- The case study results were positive since the resulting net present value was a positive value

- Recommendations to Platinum Millwork with respect to the case study were either within or outside of this project's scope

- In order to make smart choices in selecting CNC router bits, its physical and operational variables need to be understood

- Economic anlysis such as cost-benefit analysis is not completely correct since there were assumptions like continuous machining hours over a one-year period

Table of Contents

1.0 Introduction

Wood cutting tools were used before the stone-age and have evolved along with the development of available materials such that they form a vital part of the automated, high-speed precision manufacturing operations in today's world (R. Furst, 2008).

In a machining operation, there are three parameters. These include quality, productivity, and economics, all of which must be addressed to optimize the machining process. These parameters, furthermore, can be affected by variability in the material to be cut, the machinery used, the selection of machine tools, and the operator's ability to perform an operation (R. Furst, 2008).

In the wood products manufacturing industry, the main objective for a machining operation is to achieve an optimal cutting result in the shortest possible time with minimal cost and waste (J. Ratnasingam, T. P. Ma, & M. C. Perkins, 1999). In order to achieve this goal capital expenditure is required mainly in the acquisition of machinery and machine tools. In the 20th century, when wood, a natural resource, was abundant, the furniture industry's central focus in saving cost and increasing productivity relied on finding low cost raw material and labor. Going into the 21st century, the supply of wood resources has become a growing concern. Environmental issues, such as global warming, and the industry's desire to save cost and enhance productivity has resulted in the need to address in optimization of machining processes (J. Ratnasingam et al., 1999). However, investment in machinery can be significant for small to medium-sized companies and could affect the company's survival at poor economic times. On the other hand, machine tools, such as computer numerical control (CNC) router bits, are far less expensive and, therefore, investment in optimization of machine tooling is far more feasible and will return improved results in quality, productivity, and economics of a machining operation.

The significance of optimization of tooling, in general, can be realized through the concept of high-performance machining. An advantage of high-performance machining is that acquisition of new machinery, which can be a heavy burden particularly for small business owners, is not a necessity in improving performance; rather, high-performance machining puts efforts into improving an existing process by minimization of machining time and optimization of the overall machining process. Therefore, high-performance machining can be achieved best through optimization in tooling, not only because of its easy adaptation to specific applications, but also because the machine tooling system is a decisive factor in controlling the performance level of machining and manufacturing (B. P. Erdel, 2003).

In any investment activities, investors will ask a simple question: whether their investments could make them wealthier. To answer this question, a net value of an investment can be evaluated through the techniques of economic analysis. In various industries, economic analysis is used to support in a decision-making process to choose an optimal solution between different alternatives (P. Duignan, 2009). There are six major types of economic analyses, including basic costing, cost minimization, cost consequence, cost effectiveness, cost utility, and cost benefit. To measure the most “immediate impact on decision-making”, cost benefit analysis is best suited to provide the most direct suggestion towards a decision (K. Frick, 2007).

Machine tools such as saw blades, cutter-heads, or router bits, have short life expectancies compared to those of the relevant machines, at which the tools are attached to. In this report, the life expectancy of CNC router bits and its effect on a company’s capital budgeting will be analyzed. Considering the short duration of a router bit’s life expectancy, cost benefit analysis has been used to evaluate an investment in an alternative type of CNC router bits, and provide supporting evidence for a case study in determining an optimal choice between two different types of CNC router bits.

2.0 Significance of Tooling in CNC Operation

To gain a better understanding of the details of CNC router bits, a general concept of CNC machining will be explained in this section.

In Roger Martin and Michael Porter’s article, “Canadian Competitiveness: Nine Years after the Crossroads”, the authors state that competitive advantage in business can be achieved through invention of unique products and processes (R. L. Martin & M. E. Porter, 2000). The Canadian wood products manufacturing industry certainly followed an effective direction by embracing the introduction of CNC machining.

Modern CNC machinery has evolved from the invention of numerical control (NC) machines by John T. Parsons in the late 1940s (Cutting Tool Engineering, 2005). A major change from the advent of CNC machines was the use of personal computers to instruct and control the movements of a CNC router. With integration of computer-aided design (CAD) and computer-aided manufacturing (CAM), along with the ability to transmit and read digitally delivered data to CNC machinery, modern CNC machines have become essential in promoting automated machining processes (H. A. Youssef & H. El-Hofy, 2008). Ranging from small and medium-sized businesses to large corporations in the wood products industry, the introduction of CNC machining has benefited numerous manufacturers by eliminating drawbacks that were present in traditional manufacturing processes. Examples of benefits in CNC machining include accurate consistency in quality, increased productivity due to shortened lead time and reduced downtime, and labor cost savings as a result of less dependency upon highly skilled workers (H. A. Youssef et al., 2008).

As the demand for CNC routers has grown, so has the demand for CNC router bits. Stationed in a tool holder, CNC router bits are machine tools that are capable of performing various machining applications such as cutting, drilling, or milling.

Machine tools can vary in their complexity in design and the material used to construct the tools. Depending on the design and material of the tools, machining operations can be affected in terms of cutting quality, productivity efficiency, and job costing. Another feature that makes tooling the most promising factor in high-performance machining is its favorable price/performance ratio. While Erdel (2003) argues that machining processes are mainly comprised of machines and machine tools, he states that “tooling traditionally only makes up less than 20% of the total production cost, it conversely directly influences the other 80% of the production cost” (p. 10). In other words, machine tools are relatively low in cost but capable of improving overall machining performance at a greater factor (B. P. Erdel, 2003).

3.0 Variables of CNC Router Bits and its Effects on Machining Parameters

This section discusses how variables of CNC router bits affect the performance of machining parameters including productivity, quality, and economics.

The finest CNC router may not produce an excellent cutting quality when a relatively inferior router bit is used for machining (L. Bird, 2006). According to research findings, American manufacturers invest a large amount of capital expenditure in the acquisition of superior machinery while equipping machines with outdated tooling. As a result, the longevity of the tools is low, increasing downtime and thus, the production cost (B. P. Erdel, 2003).

It is for these reasons that optimization of tooling should be carefully considered. There are two categories for variables of CNC router bits including the bits’ physical properties as well as variables that characterize the bits’ operation. CNC router bits’ performances are affected by the variability in the router bits’ cutting edge material, number of flutes, design in knife arrangement, diameter, and cutting angles. The operational variables include feed rate, RPM, and cutting depth.

Since end mills are used extensively in CNC routing for milling and turning purposes, and because end mills have been the focus of the case study analysis presented later in the report, this report will use end mills as an example of CNC router bits to describe the design and features that constitute a router bit.

3.1 Variability in Productivity

Although a CNC router bit can be different from another by design and features, the general layout of tool geometry is the same for router bits with the same purpose. The figure below shows the physical properties of a CNC router bit in a simple design. However, CNC router bits with different features, such as the number of flutes or cutting edge material, operate under varying levels of productivity due to different recommendations for the router bit's optimal feed speed and RPM.

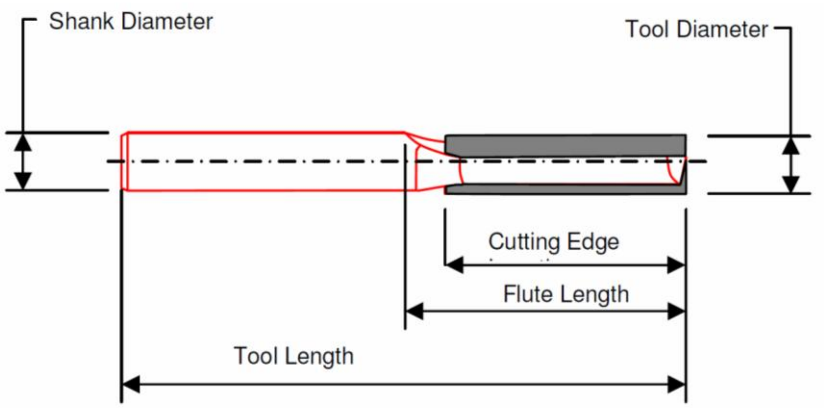


Figure 1. Tool Geometry of a CNC Router Bit (P. Cramond, 2011)

Variables that pertain to productivity of a machining process can be related mathematically in several formulas, which are described below.

Feed rate is the velocity relative to the movement of a router bit. Measured in distance per unit of time, feed rate is directly connected to machining productivity. The relationship between feed rate and other variables can be considered in the following formula:

$\text{Feed Rate (in. per min.)} = \text{RPM} \times \text{Number of Cutting Edges} \times \text{Chip Load}$ (BC Saw & Tool, 2008).

RPM stands for revolutions per minute or the spindle speed, number of cutting edges refers to the number of flutes, in which a flute is a pair of cutting edges, and chip load refers to the amount of stock removed per cutting edge in machining (L. Bird, 2006). Mathematically, feed rate is directly proportional to the other three variables; hence, an increase in any one of the three variables will increase the feed rate accordingly. This formula also makes sense intuitively since a higher spindle speed and greater number of cutting edges will remove more material per machining. As a result, the relative speed, in which the router bit moves along the work piece, will increase (Wikipedia, 2011).

The feed rate formula can be rearranged to determine the chip load of a machining process and expressed as the following formula:

$\text{Chip Load (in. per tooth)} = \frac{\text{Feed Rate}}{\text{RPM} \times \text{Number of Cutting Edges}}$ (BC Saw & Tool, 2008).

Mathematically, chip load is directly proportional to feed rate, but inversely proportional to the RPM and number of cutting edges. This is also intuitively true since as the number of flutes increase, the contact area between the cutting edge and work piece becomes smaller per cutting edge. Therefore, the chip load will decrease as the number of cutting edges increases.

While feed rate would obviously be increased to increase productivity, the cutting speed of the cutting edge determines the rate at which the amount of stock is removed (J.

Ratnasingam et al, 1999). The relationship between cutting speed and its variables is expressed as the following formula:

$$V\ (\text{feet per second}) = \frac{\pi \times D \times R}{12 \times 60},$$

where V represents the peripheral cutting speed of the router bit, D for the bit diameter, and R the RPM (J. Ratnasingam et al., 1999). According to the formula, the cutting speed is directly related to the bit's diameter and RPM. Hence, a greater spindle speed and a larger diameter router bit will increase the cutting speed. To understand the reason behind this relationship, a simple analogy will be used. Cutting speed is also known as surface speed because cutting speed measures the speed at the outer edge of a tool as the tool revolves. For example, a larger diameter wheel would travel further than a smaller wheel if both wheels were rotating at the same speed. The reason is because the larger wheel has a larger diameter, which provides greater surface area (Fox Valley Technical College, 2000). Therefore, the cutting speed of a router bit depends on the diameter of the bit.

Perhaps the most critical decision-making factor in tooling is tool tipping or the use of different raw materials to construct a cutting edge. This includes tool steels, hard metals, cast non-ferrous alloys, ceramics, and diamonds, each and every category of raw materials that determine the life expectancy of router bits during their use in tool tipping. Although the feed rate and cutting speed have a direct influence on productivity, machining productivity can also be measured indirectly through production loss-time due to time consumed in tool changing. For example, carbide-tipped router bits typically last 20 to 25 times longer than router bits tipped with high-speed steel (HSS) (L. Bird, 2006). This is because of the difference in the tool's wear resistance due to the difference in the nature of the raw materials. Based on the duration of the router bits, the HSS bit will require 20 to 25 more replacements or tool changes. In annual terms, the sum of non-productive machine time derived from tool changes could result in quite a large productivity loss. In order to minimize this loss, selection of router bits should be based on the tool's wear resistance factor and life expectancy.

Therefore, decision-making in selecting a router bit in favor of productivity depends on the router bit's recommended feed rate and RPM, the bit's specified cutting speed, number of cutting edges, chip load, bit diameter, and tool tipping.

3.2 Variability in Quality

A measure of quality in a machining process refers to an evaluation in the quality of the finished machined surface. Similar to evaluating productivity, a resultant surface quality in machining can also be expressed in mathematical terms.

The surface quality of a work piece in machining is largely dictated by the number of cuts per inch, which is expressed in the following formula:

$$P\ \text{inches} = \frac{12 \times F}{N \times R};$$

In the formula above, P stands for pitch length, F for feed rate, N for the number of cutting edges, and R for RPM. According to research, the resulting surface quality of a work piece is expected to improve as the P value becomes smaller (J. Ratnasingam et al., 1999). However, a smaller P value has less significant meaning by itself with regard to quality, and the following example will aid in understanding the above formula more easily. Assuming all else being equal[1], consider a router bit running at 67 feet per minute while another bit is running at 75 feet per minute. Simply calculating for P for both router bits, consider the following results.

$$\text{Router bit A: } P = \frac{12 \times 67}{3 \times 18{,}000} = 0.01488;\ \text{Router bit B: } P = \frac{12 \times 75}{3 \times 18{,}000} = 0.01667;$$

The above results can be interpreted that router bit A is performing approximately 67 cuts per inch (1/0.01488) whereas router bit B is producing about 60 cuts per inch (1/0.01667). Theoretically, router bit A, which is running at a lower feed rate than router bit B, should have a better resultant surface quality since a greater number of cuts per inch result in a smoother surface.

The most critical variable of CNC router bits in determining the cutting quality may be the design and arrangement of the cutting edge and the resultant cutting angles. For a clearer understanding of the relationship between cutting angles and cutting quality, cutting angles of CNC router bits will be described as follows. The figure below shows the major cutting angles of a router bit.

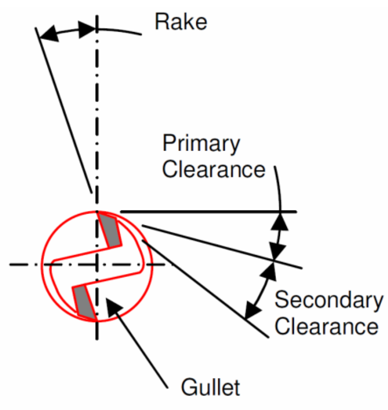


Figure 2. End Mill Router Bit from Top View (P. Cramond, 2011)

From the above diagram, the rake angle is the angle between the face of the cutting edge and a line perpendicular to the feed direction. The rake angle, also known as the cutting angle, is the major angle for determining the cutting quality. The rake angle

[1] This assumption applies to all examples presented throughout this report.

varies in order to produce an optimal cutting quality depending on factors such as the moisture content and species of wood (R. Furst, 2008). In general, a smaller rake angle is necessary when cutting kiln-dried wood compared to air-dried wood due to the difference in hardness. Depending on the wood species, the required rake angles vary (see Appendix A) due to the variations in the type of grain and growth pattern (R. Furst, 2008). The clearance angles also play an important role in determining the quality, efficiency, and life expectancy of the cutting edge (R. P. Pohanish & C. McCauley, 2000). According to Pohanish and McCauley (2000), “it is desirable in all cases to use a clearance angle as small as possible” (p. 131), since a greater area of the back bevel of a cutting edge can be used to provide better dispersion of heat as well as greater support to the cutting edge (R. P. Pohanish et al., 2000). Furthermore, extreme clearance angles, promote occurrences of chatter, which results in a reduced life expectancy of a CNC router bit due to the weakening of cutting edges. Chattering also degrades the quality of a machined surface. The figure below shows a better representation of the angles on a cutting edge of a router bit.

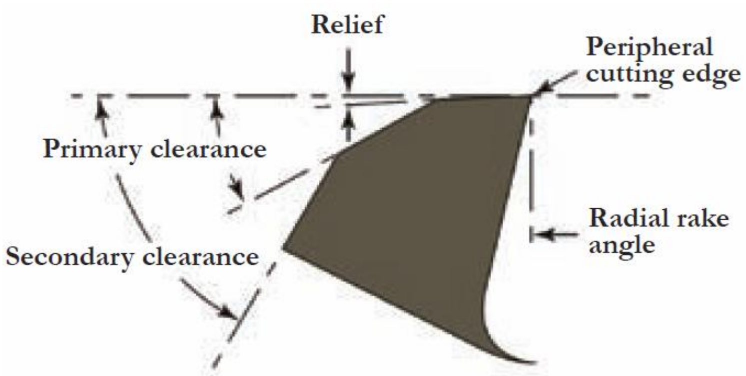


Figure 3. Magnified View of a Router Bit Cutting Edge and Associated Cutting Angles (Grinding Journal, n.d.)

For best quality results, cutting edges on a router bit are slanted on an angle to produce cuts along the shear plane, also known as shear cuts. Compared to straight cutting edges, the cutting edges that employ shear angles are able to create a shearing effect, which prevents machining defects, such as tear outs or splinters, and results in a clean-cut surface (L. Bird, 2006).

Prior to further explaining the influence of router bit design on machining quality, it is important to understand what shear angle and shearing effect are. The terms, shear angle and shearing effect, are closely associated with the formation of chips and the types of chip formation. The figure below shows the motion of chip load as the cutting edge shaves in the feed direction relative to the workpiece.

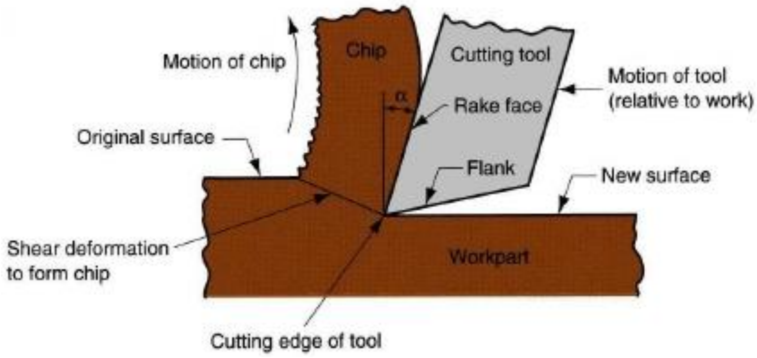


Figure 4. Rake and Shear Angle Three (M. P. Groover, 2007)

Largely dictated by the rake or cutting angle, α (alpha), shear angle is the angle between the maximum shear plane and the plane parallel to the workpiece as shown in the figure below (M. P. Groover, 2007). Consider the following figures below to see that the change in the degree of rake angle is directly proportional to that of the angle on the shear plane.

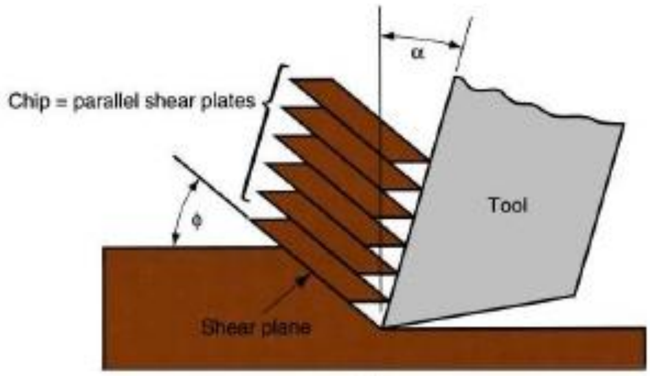


Figure 5. Rake and Shear Angle One (M. P. Groover, 2007)

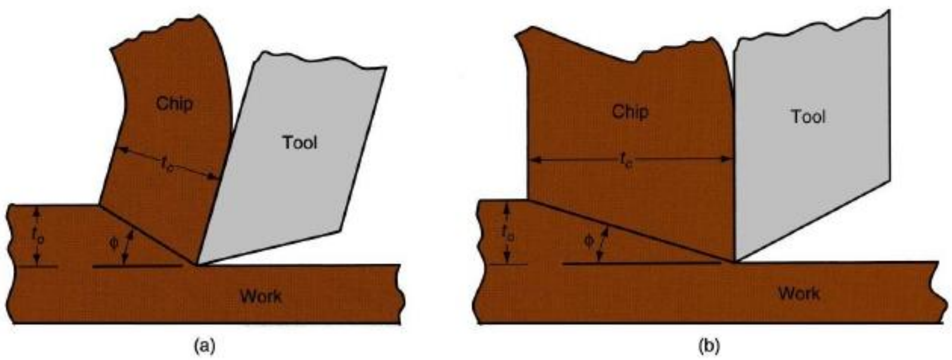


Figure 6. Rake and Shear Angle Two (M. P. Groover, 2007)

As illustrated in *Figure 5*. and *Figure 6*., where ϕ depicts the angle from the shear plane, this angle increases in accordance with the increase in the rake angle. Comparing (a) and (b) of *Figure 6*., the angle of shear plane is higher in (a) than (b) while rake angle in (a) is also higher than the one in (b).

Depending on the cutting angles, a desired shear angle can be achieved, which results in different types of chip formation. When the rake angle is too high, a thick load of chip is shaved, and the tendency for the wood to split increases. This especially occurs when machining against the grain under this condition, and splitting of chips causes lumps of wood to be removed, and a surface defect known as tear-out occurs. This chip formation is called the Type I chip formation (S. Elliot, 2005).

Type II chip formation takes place when the rake angle is set so that the "wood is cut right at the sharp edge of the blade", forming thin slices of chip load (S. Elliot, 2005). When this cut takes place on the work piece, wood fibers are forced to bend until failure occurs. The bending force causes the fibers to "slide against each other", and generate a shearing effect (S. Elliot, 2005). The shearing effect causes the chips to lose their stiffness as they bend, and reduces the chance for the wood to split and leave a surface defect (S. Elliot, 2005). Therefore, effective shear angle and shearing effect definitely improve the resultant surface quality. Illustrations of Type I and Type II chip formations can be considered in the figures below.

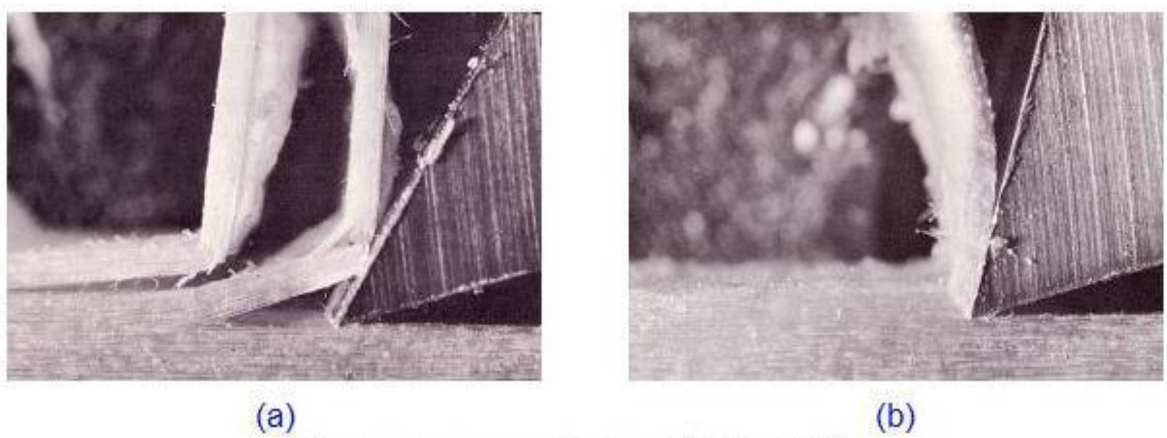


Figure 7. (a) Type I Chip Formation (b) Type II Chip Formation (P. Cramond, 2011)

Based on the outcome in cutting quality from router bits with slanted cutting edges that produce a shearing effect, spiral bits are expected to produce the best resultant cutting quality. Unlike straight router bits, spiral bits have cutting edges that incorporate a shear angle[2] on each cutting edge. While straight flute router bits are generally a good choice for routing softer materials, spiral router bits are good for routing all materials as their cutting edges provide shearing effect to the work piece and leave a smooth finish (Royce//Ayr Cutting Tools Inc., 2010).

Another design feature of CNC router bits that pertain to cutting quality is the router bits' design in chip flow. Spiral router bits have three styles of chip flow designs including

[2] This shear angle relates back to the angle from the shear plane that creates shearing effect.

up-cut, down-cut, and compression cut (P. Cramond, 2011). While up-cut router bits lift the chips upward to provide good cutting quality on the bottom finish, the top surface is expected to have a poor finish with possible surface defects such as tear outs. The expectation of down-cut router bits would be the opposite of up-cut bits. With down-cut router bits, the chip flows downward to provide the best quality on the top surface. The figures below show the difference in design between straight and up and down-cut spiral router bits.

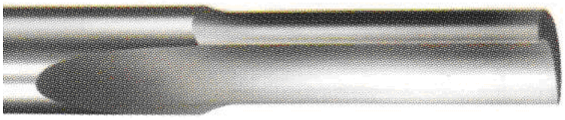


Figure 8. Straight Router Bit with No Shear Angle (P. Cramond, 2011)

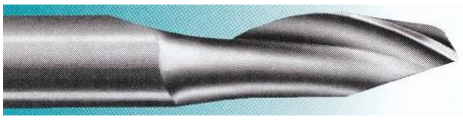


Figure 9. Up-Cut Router Bit Single Spiral (P. Cramond, 2011)

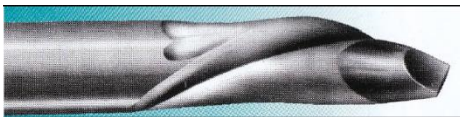


Figure 10. Down-Cut Router Bit Single Spiral (P. Cramond, 2011)

Lastly, compression style router bits are expected to provide good cutting quality on both top and bottom surfaces. This is because the design of compression bits can accommodate simultaneous chip flows in an upward direction as well as in a downward direction. Thus, compression router bits are the most suitable bits for machining work pieces that have plastic coverings such as a melamine or a laminate (Royce//Ayr Cutting Tools Inc., 2010). Below is a figure of a compression router bit.

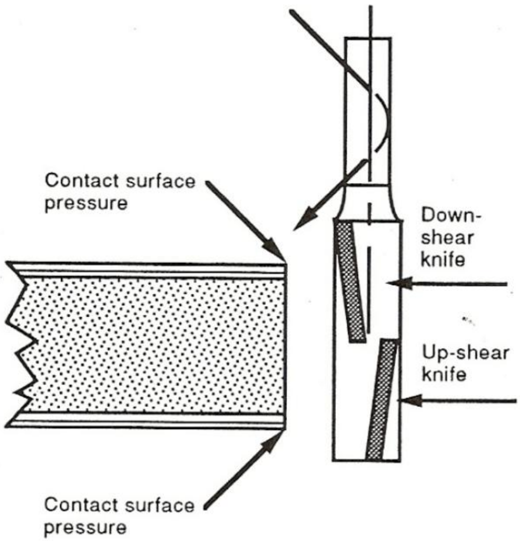


Figure 11. A Sketch of Compression Router Bit (P. Cramond, 2011)

The last feature in the design of router bits that influences cutting quality would be the chip-breaking mechanism by chip-breakers on the bits. Upon chip formation, chip-breakers enhance performance of multiple cutting edges (R. Furst, 2008). By supporting the cutting edges in breaking off the chips upon cutting, chip-breakers produce a shearing effect when the edge of a chip-breaker is parallel to a diagonal plane where the chip is bent. Through compression, a shearing stress is applied between the edge and the plane. Similar to when a cutting edge cuts a work piece, the chip-breaker forces the wood fibers to slide against each other creating a shearing effect. Due to the shearing effect, chips are forced to be pushed back and bend more sharply on the shear angle plane (S. Elliot, 2005). Chip-breakers, therefore, are good additional features to CNC router bits in order to improve the resultant quality.

In brief, the resultant machining quality depends mainly on the number of cuts per inch or the pitch length, variability in design and arrangement of cutting edges, and the associated cutting angles. In the next section, economics in tooling with regard to CNC router bits will be looked at.

3.3 Variability in Economics

When the cost of a CNC router bit is higher than another, it does not necessarily mean that the more expensive router bit has a greater value for all CNC machining. There are different types of router bits with different features to achieve different goals. CNC router bits are mainly differentiated by the number of flutes[3], the cutting edge design, the presence of shear angle on the cutting edges, and the material used to construct the cutting edge. Essentially, alike other machine tools, buyers need to make smart decisions in purchasing CNC router bits by taking into account the purpose of a CNC application as well as the router bit's price to performance ratio.

The tool diameter and number of flutes are similar in economic terms. According to Pat Cramond (personal communication, April 9, 2011), router bits with larger tool diameters can reduce the number of passes required for end milling; furthermore, for CNC applications (i.e., grooving) that require larger bites, larger tool diameters allow deeper cuts as they also have larger gullets[4]. Finally, larger tool diameters create available space to accommodate a greater number of flutes on router bits. However, an increase in either the tool diameter or number of flutes results in a higher manufacturing cost of router bits. Moreover, there are CNC operations that do not require the benefits of using larger tool diameter router bits. For example, single flute router bits carry large gullets and thus, a greater chip load, which is a significant factor for using these router

[3] Flutes refer to cutting edges on CNC router bits; depending on the cutting edge design, flutes can either refer to a single or pair of cutting edge (i.e., sprial router bits have flutes that can be described as pair of cutting edges).

[4] Gullets collect and release chip waste.

bits in wide grooving applications at high speed (P. Cramond, 2011). Nevertheless, an increase in the number of flutes increases the feed speed and, therefore, productivity. In peripheral milling, more numbers of flutes reduce the pitch length, which increases the number of cuts per inch, and results in an improved surface quality. Even so, various CNC applications demand different levels of tooling based on the application's requirements, while undesirable costs can occur if only the most expensive CNC router bits are considered without taking into account the price to performance ratio.

The overall design of CNC router bits is also a major factor in determining the cutting quality and cost in tooling. Spiral router bits can produce a better surface quality than straight router bits by employing shear angles on the cutting edges, but result in greater cost due to the complexity in manufacturing. While straight router bits are lower in cost, the straight router bits are generally a good choice for finishing the outer edges of a work piece due to the absence of axial forces, at which helps to clamp the work piece (P. Cramond, 2011). A similar case can be considered between single and multi-spiral router bits. For example, to acquire an excellent finish on the top and bottom laminate surfaces of particleboard core, the operation may require a three-flute compression router bit with chip-breakers. However, to acquire a satisfying finish only on the top surface, a single spiral up-cut router bit will be good enough for the operation. Therefore, manufacturers should not to be making hasty decisions in purchasing high-end router bits since even a single flute straight-cut router bit can produce a satisfactory finish on both the top and bottom surfaces, depending on its usage and application (Royce//AYR Cutting Tools, 2010).

Perhaps, the most critical variable in tooling is the raw material used to construct the cutting edge. A router bit's cost, life expectancy, and productivity are largely affected by tool-tipping. Take for example synthetic polycrystalline diamond (PCD) tipped router bits; the longevity of PCD router bits – later identified in the case study – is 30 to 55 times longer than that of carbide tipped router bits depending on the frequency of use of the router bits. In addition, PCD router bits are four times harder than carbide router bits, which makes PCD bits perfect for machining medium density fiberboards (MDF) and other engineered composites such as particleboards (R. Furst, 2008). Also presented in the case study, is the fact that the initial cost of PCD router bits is at least six times higher than the cost of a carbide router bit. It is true that purchasing a dozen of PCD router bits may be too expensive, especially for small-size business owners; however, the long-term cost of PCD router bits has proven to be more economical as shown later in the case study via cost-benefit analysis. Under the assumption that CNC machining is constantly being used in production, carbide router bits would require a much greater number of tool replacements compared to PCD bits. This lost-time in production not only decreases productivity, but also results in greater cost. In annual comparisons, the total accumulated cost of using carbide router bits could outweigh the total cost of using PCD bits. In terms of indirect cost, the loss-time created by tool changes corresponds to loss in monetary value in overhead cost of production.

Therefore, economic analyses such as cost-benefit analysis can be applied to evaluate and compare the net worth of different tooling solutions. In the next section, fundamentals of cost-benefit analysis will be covered.

4.0 Cost-Benefit Analysis: Effective Evaluation of an Investment

Cost-benefit analysis (CBA) is a process mainly used to evaluate and compare costs and benefits of two or more different alternative approaches to the same problem. CBA provides objective comparisons between different projects by presenting all costs and benefits in monetary terms. While the concept of CBA seems intuitive, in practice it often requires various assumptions in monetizing costs and benefits of goods and services that do not have a market value (J. Roman, 2010). For example, an increase in productivity of a machining operation is difficult to monetize since productivity is normally not measured in a dollar value. However, a huge advantage of CBA over cost-effective analysis (CEA) or cost-utility analysis (CUA) is that a broader range of alternatives can be compared since all outputs are in dollar values (G. M. Guess & P. G. Farnham, 2000). The fact that all costs and benefits are expressed in dollar terms makes decision-making easier because it reduces the qualitative elements incorporated into the analysis. Furthermore, since the monetized outputs of costs and benefits are forecast over the project duration, the time value of money is applied. The time value of money is based on a dollar today carrying a greater value than a dollar in the future even without the effect of inflation because today's dollar can be used productively while money in the future cannot (Government of California, 2007). The expected cash flows in costs and benefits are discounted to its present value, by which several projects with varying duration can compare their net worth on a common basis (Wikipedia, 2011). Discount rates are chosen to discount future cash flows of a project, and can be viewed either from a borrower's or lender's perspective.

In measuring the economic efficiency of various projects, the net worth of costs and benefits are determined by computing each project's benefit-cost ratio (BCR) and net present value (NPV).

The formula for calculating the benefit-cost ratio is expressed as follows:

$$BCR = \left(\frac{B_i}{(1+d)^i}\right) \div \left(\frac{C_i}{(1+d)^i}\right) \text{ where i = 0 to n;}$$

In the above formula, n is the number of years under consideration, B_i is the total of the benefits from years, i = 0 to n, where i is a specific period of year within the total number of years under consideration, C_i is the total of the costs, and d, is the discount rate over the years under consideration. When BCR is greater than 1, it means that the project's benefits are greater than its costs, and the net benefit value is positive. One major problem that could occur from using BCR is that the ratio is insensitive to the dollar value; the BCR may favor the project with a higher ratio value even when another project has greater net benefit in monetary terms (Government of California, 2007).

The formula for calculating the NPV in a CBA is expressed as follows:

$$\text{NPV} = \left(\frac{B_i}{1+d\ ^{i}} \right) - \left(\frac{C_i}{(1+d)^{i}} \right);$$

By determining the NPV, the project is acceptable as long as the NPV is positive. Since NPVs are presented in monetary terms, the NPV eliminates the issue of the BCR not being able to quantify the results in a dollar value. Even when a project has a lower BCR, the project that has the highest NPV is most favorable. Therefore, although both BCR and NPV can be used in a CBA, determining the NPV will always result in greater accuracy in decision-making (Government of California, 2007).

In the following case study, CBA will be used to justify a replacement decision of CNC router bits for a kitchen cabinet manufacturer.

5.0 Case Study: Alternative Tooling Solution for Platinum Millwork's CNC Router Bits

The objective of this case study was to approach a kitchen cabinet manufacturer with an alternative tooling solution to CNC router bits, and incorporate CBA to determine the acceptance of a replacement decision.

5.1 Case Study Proposal

Platinum Millwork is a small-sized, growing company active in kitchen cabinet manufacturing as well as architechtural and custom millworking. The company uses computer aided design (CAD) for product design and computer aided machining (CAM) by utilizing a CNC router in production. Since Platinum was using solid carbide router bits, Platinum's router bits were identified as good candidates in comparison to PCD router bits. Platinum's future decision in accepting the replacement decision depended on whether a change to PCD tipped router bits would save cost in the long-term while offering greater benefits than before in terms of productivity and quality.

5.2 Case Study Process

The first part of the process was to find out about the current information regarding Platinum's CNC router bits. At the time, Platinum was using six types of router bits. The first router bit that I encountered was used for cutting melamine material both on the top and bottom sides with particleboard core. The router bit was a three-flute compression spiral bit that was tipped with solid carbide. Since this router bit has been used most frequently, it was used as a basis for comparison to PCD router bits. The second router bit was used for cutting plywood. This router bit had identical characteristics as the bit for cutting melamine, but was equipped with chip-breakers.

The third and fourth router bits were three-flute up-cut solid carbide bits with slanted cutting edges[5]. Both router bits were used for machining solid surfaces such as corian, but the smaller diameter bit was used for cutting applications, while the larger diameter bit was used for grooving and dadoing applications on solid surfaces. The last two router bits were insert-types; the "V" shaped bit was used for tapering applications while the four-inch diameter bit (largest of all router bit types in Platinum) was used to make smooth surfaces on the spoiler board on the CNC router. Since insert-knives were low-cost, but these insert-type router bits were not being used frequently, I decided not to find a replacement for these bits. All router bit types being used at Platinum shared a common basis in terms of the life expectancy of the router bits[6]. Under constant CNC machining, each router bit held production capacity of machining approximately 240 sheets of material for as long as 67.2 hours of cutting time.

In response to delivering the above information to Quality Saw and Knife, I was informed that diamond-tipped router bits last from 30 to 55 times longer than Platinum's carbide bits, depending on the frequency of usage and the material of the work piece. In order to match the requirements at reasonable pricing with PCD router bits, I had to acquire more specific details including the feed rate, RPM, the exact measurement of bit-diameter and required cutting length, and the initial and maintenance costs of Platinum's router bits. After acquiring the required information from Platinum and reporting back to Quality Saw and Knife, I was able to find out that there were two PCD router bits that were capable of replacing Platinum's four solid carbide bits. The first PCD router bit is able to replace two carbide bits for machining melamine and plywood while the second PCD bit can replace the two bits for machining solid surfaces.

With the information obtained from Quality Saw and Knife, I was able to present the following information.

The tables below illustrate quantitative data comparisons of the router bits.

Table 1. Comparison of Router Bits for Cutting Composite Material

Tooling Variables	Vortex 3289 VIPER	Vortex VIPER+ 3289c	Royce DIA-HIFEED.06
Tool Tipping:	carbide	carbide	diamond
Machining Application:	cutting melamine material with PB core	cutting plywood composites	can cut melamine, particleboard, and plywood
Number of Flutes:	3	3	3
Knife Design:	Compression and Spiral	Compression and Spiral	Compression and Spiral
Bit-Diameter:	½"	½"	¾"
Cutting Length:	30 mm	30 mm	35 mm

5 Refer back to cutting edges with shear angles described in a previous section.

6 Information based from Victor De Fazio, the president of Platinum Millwork.

Feed Rate:	25,400 mm/min or 1,000" per min.	27,000 mm/min or 1,063" per min.	20,320 mm/min or 800" per min. (recommended)
RPM:	16,000 rpm	16,000 rpm	18,000 rpm (recommended)
Initial Cost:	$123.00	$150.00	$687.31
Sharpening Cost:	$40.00	$40.00	$240.00
Max. # of Sharpenings:	3	3	5 to 6 depending on machining frequency
Life Expectancy (constant usage):	67.2 hours	67.2 hours	2,016 hours[7]
Production Capacity:	240 sheets	240 sheets	7,200 sheets
Additional Feature:	N/A	Chip-breaker	N/A

Since the diamond router bits have not been used at Platinum yet, the actual life expectancy as well as maintenance will vary depending on how often the router bits are used as well as what the core material of work piece is (i.e., MDF, particleboard, plywood, and etc…). In general, the higher the density of wood to be cut, the faster the tool wears out. Feed rates of the PCD router bits shown in both tables have starting points as recommended feed rates. For the Royce Custom Bit, the maximum allowable feed rate has been specified; however, with the Royce DIA-HIFEED, the maximum allowable feed rate is recommended to be reached gradually until poor cutting quality is resulted (Amana Tool, 2010). Due to these reasons, the life expectancy, amount of maintenance required, as well as production capacity of the diamond router bits had to be calculated based on the known life of WC tools and the ratio of PCD to WC tool life expectancies.

Table 2. Comparison of Router Bits for Machining Solid Surfaces

Tooling Variables	Vortex 4400 Three Flute Low Helix Up-cut Finisher	Vortex 4400 Three Flute Low Helix Up-cut Finisher (larger bit)	Royce Custom Bit
Tool Tipping:	carbide	carbide	diamond
Machining Application:	cutting solid surfaces such as corian	grooving and dadoing solid surfaces	can cut, groove, and dado on solid surfaces
Number of Flutes:	3	3	3
Knife Design:	up-cut and helical	up-cut and helical	compression and spiral
Bit-Diameter:	½"	¾"	¾"
Cutting Length:	25 mm	62 mm	40 mm

---

7 Depending on the frequency of machining and the core material of the work piece, the life expectancy and production capacity of PCD router bits are 30 to 55 times greater than the carbide router bits.

Feed Rate:	12,570 mm/min or 495" per min.	10,800 mm/min or 425" per min.	13,970 to 20,320 mm/min or 550" to 800" per min.
RPM:	15,000 rpm	16,194 rpm	18,000 rpm (recommended)
Initial Cost:	$160.00	$230.75	$1,116.64
Sharpening Cost:	$29.95	$47.40	$375.00
Max. # of Sharpenings:	3	3	5 to 6 depending on machining frequency
Life Expectancy (constant usage):	67.2 hours	67.2 hours	2,016 hours
Production Capacity:	240 sheets	240 sheets	7,200 sheets
Additional Feature:	N/A	N/A	Chip-breaker

The greatest challenge that occurred in the entire process was the size of the router bit-diameter. While the original plan for diamond router bits was to use ½" diameter bits with two flutes, the feed rates of these router bits were insufficient to match the feed rates of Platinum's three flute bits. However, increasing the number of flutes on ½" diameter bits was not feasible due to a lack of surface area to construct another flute on the bit. Therefore, it was decided that the PCD router bits' tool diameter should be ¾"[8]. Due to this increase in tool diameter from ½" to ¾", an additional ¼" of stock removal can be expected per sheet along the total distance that the router bits will travel. The additional amount of stock removal will result in material loss proportionately since Platinum was functioning with ½" carbide router bits. Furthermore, although productivity and quality are expected to improve due to the increase in the number of flutes, the cost of the PCD router bits have increased accordingly[9].

For drawings of the first PCD router bit, refer to Appendix C.

The final part of this case study was to conduct a CBA of replacing Platinum's carbide bits with PCD router bits, and determine the acceptance of investment in PCD router bits from Quality Saw and Knife.

5.3 Cost and Benefit Analysis on Alternative Tooling Solution

In this CBA, NPV calculation will be used to assess the net worth of cash flow. However, since annual profit is neglected in this project, all NPVs may be negative values, and the acceptance of investment on PCD router bits could depend on whether the use of PCD router bits saves greater costs in production.

---

[8] In consideration of excessive material loss, 1" tool diameter was rejected, but ¾" tool diameter was feasible.

[9] This price change pertains to the previous model (lower cost) suggested from Quality Saw and Knife.

The first part of the CBA looks at all of the costs associated with tooling of CNC router bits. Both carbide and diamond router bits require an initial cost, replacement costs, and maintenance costs.

As the second part of CBA, the benefits analysis looks at any positive changes that occur from an alternative solution. However, not all benefits can be measured in monetary terms, and some benefits will have to be left unidentified.

In this project, the greatest benefit of employing PCD router bits is the reduction in the number of replacement periods or tool changes. The number of tool changes is closely associated with the overhead cost, which is the cost of operating and maintaining the work place. During a tool change, whether the CNC router is operating or not, the overhead cost is being charged constantly throughout the year. Therefore, the greater the number of tool changes, the greater the loss in productivity of CNC machining, and the increase in the overhead cost.

Refer to Appendix B for all calculations of costs and benefits as well as for solving for the BCR and NPV.

The tables below shows the summation of the calculated results.

Cost Analysis

CNC Router Bit	NPV
Vortex 3289 VIPER	-$7,309.59
Vortex VIPER+ 3289c	-$8,001.76
Vortex 4400 Three Flute Low Helix Up-Cut Finisher	-$7,425.79
Vortex 4400 Three Flute Low Helix Up-Cut Finisher (larger tool diameter)	-$11,102.53
Total	-$33,839.67
Royce DIA-HIFEED.06.	-$2,491.49
Royce Custom Bit	-$3,975.87
Total	-$6,467.36

Benefit Analysis

Benefit Variable	NPV
Total Loss in Overhead Cost from Using Carbide Router Bits	-$5,238.26
Total Loss in Productivity Using Carbide Router Bits	-$9,419.29
Total	-$14,657.52
Total Loss in Overhead Cost from Using Diamond Router Bits	-$259.34

Total Loss in Productivity Using Diamond Router Bits	-$470.2871
Total	-$729.6271
Total Benefit	$14,657.52 - $729.6271 = +$13,927.9229

Results

Carbide Router Bits	**Value**
Total Benefits	$0
Total Costs	-$48,497.22
Diamond Router Bits	**Value**
Total Benefits	+$13,927.9229
Total Costs	-$6,467.36
NPV	+$7,460.56
BCR	2.15

5.4 Recommendation to Platinum Millwork

The following recommendations were made to Platinum Millwork with respect to the case study.

Within the project scope:

- Based on CBA, investment on PCD router bits is acceptable since the NPV is positive and BCR is greater than 1
- Compare all other variables that were not analyzed in this case study, such as the comparison of cutting quality between carbide and diamond router bits and the associated variables that need to be addressed

Outside the project scope:

- Conduct a thorough time-study on the CNC machining at Platinum to determine the average machining time per week, month, or year
- Confirm the case study results with an expert with the least number of assumptions and incorporate uncertainty factors such as tool breakdown due to accidents
- May be secure to purchase additional numbers of router bits to carry as spares

6.0 Conclusion

Throughout the case study on finding an alternative tooling solution for Platinum Millwork, an economic analysis was performed to assess and compare the monetary values in costs and benefits of operating carbide and diamond-tipped router bits. Although an investment in diamond bits seems to be very beneficial, the acceptance of the investment really depends on Platinum's perspective on CNC machining. Also, the life expectancy of the diamond bits depends on the frequency of using the router bit as well as what the material of the work piece is. In order to eliminate these uncertainties in the CBA, there were assumptions to be made. For example, all expected cash flows presented above in the case study were projected under an unrealistic assumption that all router bits would be used constantly over a 1-year period. Furthermore, since every job is different and each job requires a different amount of CNC machining, productivity loss calculations were carried out under the large assumption that average CNC machining time per job is 8 hours. Nevertheless, incorrect assumptions would not result in extreme differences since CNC router bits of different materials are fundamentally different in terms of their productivity, quality, and economics.

In conclusion, CBA can help small to medium-sized businesses make smart decisions upon acquiring business assets. However, it is absolutely essential to understand and know the fundamental differences in alternative solutions. As in case of CNC router bits, an investment decision cannot depend only on the economics of tooling because there may be non-monetary variables that could affect the final decision.

References

Amana Tool. (n.d.). Technical Information Router Bit Selection, Application & Maintenance. Retrieved March 30, 2011, from http://www.amanatool.com/2008catalog/Technical_information.pdf

BC Saw & Tool Inc. (n.d.). CNC Tooling Solutions. Retrieved March 30, 2011, from http://www.bcsaw.com/wp-content/uploads/2010/08/CNCCatalogue.pdf

California Department of Transportation. (2007). Benefit-Cost Analysis. State of California. Retrieved March 28, 2011, from http://www.dot.ca.gov/hq/tpp/offices/ote/benefit_cost/index.html

Cost-benefit analysis. (2011). Retrieved from Wikipedia: http://en.wikipedia.org/wiki/Cost-benefit_analysis

Cramond, P. (2011). WOOD 494 Principles of Wood Cutting and Tooling course notes. Vancouver, BC: University of British Columbia

Duignan, P. (2009). Types of economic evaluation analysis. Outcomes Theory Knowledge Base. 251. Retrieved March 20, 2011, from http://knol.google.com/k/types-of-economic-evaluation-analysis#

Elliot, S. (2005). Shaving Formation. Retrieved March 27, 2011, from http://planetuning.infillplane.com/html/shaving_formation.html

Erdel, B. P. (2003). High-Speed Machining. Available from http://books.google.com/books?hl=en&lr=&id=bbmIEKZAoZ0C&oi=fnd&pg=PR15&dq=HIGH+SPEED+MACHINING+CONCEPTS+-+THE+MAN+-+MACHINE+-+TOOLING+TEAM.&ots=oXJ41EBM48&sig=ZF0FB7SyQMsM0d6sl0PJklQLv5g#v=onepage&q&f=false

Fox Valley Technical College. (2000). Lathe Cutting Speeds – RPM Calculations. Retrieved March 27, 2011, from http://its.foxvalleytech.com/MachShop2/Speeds/RPMcalc.htm

Frick, K. (2007). Concepts in Economic Evaluation [PDF document]. Retrieved from Lecture Notes Online Web Site: http://ocw.jhsph.edu/courses/ConceptsEconomicEvaluation/PDFs/Lecture1.pdf

Furst, R. (2008). WOOD 494 Principles of Wood Cutting and Tooling course notes. Vancouver, BC: University of British Columbia

Groover, M. P. (2007). Fundamentals of Modern Manufacturing Third Edition. Retrieved March 27, 2011, from http://www.scribd.com/doc/50569505/19/Determining-Shear-

Plane-Angle

Guess, G. M., & Farnham, P. G. (2000). Cost-Benefit Analysis: The Case of Environmental Air Quality Standards. Cases in Public Policy Analysis Second Edition (302-369). Available from http://books.google.com/books?id=KGFnn4KJHN8C&pg=PA304&lpg=PA304&dq=%22Flood+Control+Act+of+1939%22&source=bl&ots=Dc5oLG0mkm&sig=tXTtcTe9hPO9xYIBTseb9LO2Ndw&hl=en&ei=bjawSdavN4_HtgeNmvnaBQ&sa=X&oi=book_result&resnum=6&ct=result#v=onepage&q=discount%20rate&f=false

Mackinnon, R. (2011). COMM 473 Business Finanace course notes. Vancouver, BC: University of British Columbia

Makely, W. (2005). Numbers Take Control: NC machines. Cutting Tool Engineering. 57(8). Retrieved March 23, 2011, from http://www.cuttingtoolengineering.com/pdf/2005/0508-50anniversary.pdf

Martin, R. L., & Porter, M. E. (2000). Canadian Competitiveness: Nine Years after the Crossroads. Retrieved March 22, 2011, from http://courses.forestry.ubc.ca/Portals/125/Readings/Martin%20&%20Porter_Canadian%20Comp.pdf

Pohanish, R. P. & McCauley, C. (2000). Machinery's Handbook Pocket Companion. Industrial Press Inc. Retrieved April 16, 2011 from http://books.google.ca/books?id=pPoNZB4xqHoC&pg=PA131&lpg=PA131&dq=primary+clearance+angle&source=bl&ots=oRI77dpqG1&sig=nIfarS-flyxvY1ejRiLXXZckb-4&hl=en&ei=AomrTbvqCZH0swPq8OT5DA&sa=X&oi=book_result&ct=result&resnum=1&ved=0CBUQ6AEwAA#v=onepage&q=primary%20clearance%20angle&f=false

Ratnasingam, J., Ma, T. P., & Perkins, M. C. (1999). Producivity in wood machining processes – a question of simple economics?. Retrieved from SpringerLink Digital Dissertations.

Roman, J. (n.d.). Cost-Benefit Analysis. Retrieved from Urban Institute Digital Dissertations.

Royce//Ayr Cutting Tools Inc. (2010). Industrial Cutting Tools in HSS, Carbide, and Diamond. Retrieved march 30, 2011, from http://www.royceayr.com/assets/Uploads/2010-Royce-CNC-pg01-26.pdf

Speeds and feeds. (2011). Retrieved from Wikipedia: http://en.wikipedia.org/wiki/Speeds_and_feeds

Sowlati, T. (2010). WOOD 440 Job Costing and Engineering Economics lecture notes.

Vancouver, BC: University of British Columbia

Why Endmills Have Gotten Weird. (2008). Grinding Journal. Retrieved April 16, 2011, from
http://www.grinding.com/pages_blocks_v3/images/links/GJ_Weird_Endmills_1208.pdf

Youssef, H. A., & El-Hofy, H. (2008). Numberical Control and Computer Numerical Control Technology. Machining Technology. Machine Tools and Operations (285-343). CRC Press. Retrieved March 21, 2011, from
http://www.crcnetbase.com/doi/abs/10.1201/9781420043402.ch8?prevSearch=%2528%255Bfulltext%253A%2Bhigh%2Bspeed%2Bmachining%255D%2529%2BAND%2B%255BpubType%253A%2B109%255D&searchHistoryKey=

Appendix

Appendix A

Table 1. Variation in Required Rake Angle Depending on Wood Species and Moisture Content

Species of Wood	Green (degrees)	Air Dried (degrees)	Kiln Dried (degrees)
Ash	25	20	15
Beech	25	25	15
Birch	25	20	15
Cedar	30	25	20
Cypress	30	25	20
Douglas Fir	25	20	15
Gum	25	20	15
Hemlock	30	25	20
Mahogany	25	20	15
Maple	25	20	15
Oak	25	20	15
Pine, Yellow	25	20	15
Pine, White	30	25	20
Poplar	25	20	15
Redwood	30	25	20
Spruce	30	25	20
Walnut	25	20	15

(R. Furst, 2008)

Appendix B

Consider the following cash flow diagrams as visual aids in how cash flows are expected over a one-year term. Since the first diamond router bit from Quality Saw and Knife can replace Platinum's two carbide bits for cutting melamine and plywood, the cash flows expected from the two carbide bits will be totaled for comparison.

<u>Vortex 3289 VIPER</u>

Life Expectancy: 67.2 working hours per machining 240 sheets. The following calculation is simply converting the total number of hours expressed in months.

$$67.2 \text{ hr } \times \frac{1\ day}{8\ hr} \times \frac{1\ week}{5\ days} \times \frac{1\ month}{4\ weeks} = 0.42\ months\ \cong 0.4\ mths$$

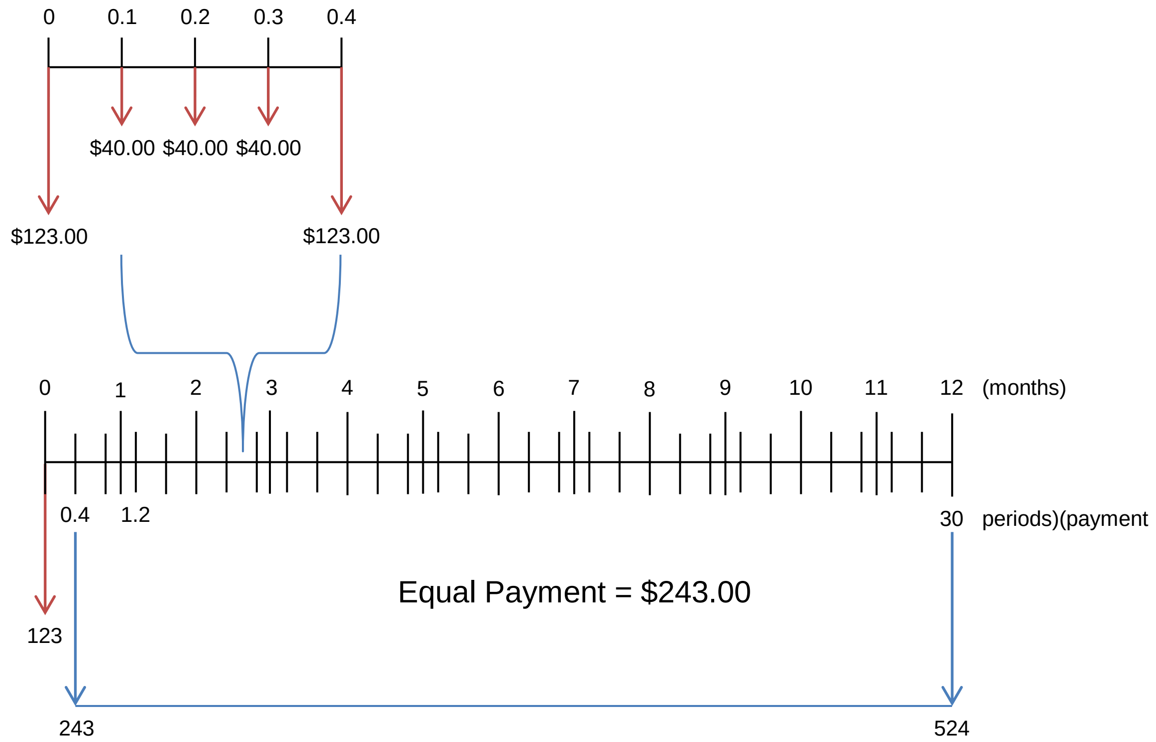
Maintenance Period: 3 sharpening required before one replacement period. Therefore, $\frac{0.4\ month}{4} = 0.105\ \cong 0.1\ month.$ So, the length of one maintenance period is approximately 0.1 month.

The below cash flow diagram illustrates all expected cash flows within one replacement period.

The total cost of using this router bit excluding the initial cost equals: $40.00\ \times 3\ + 123.00 = \$243.00.$

Assuming that 1 replacement period comes in 0.4 month, the total number of replacements required in a year equals: $\frac{12\ month}{0.4\ month} = 30\ replacement\ periods\ per\ year.$ The formula above is stating that each tool change takes place in 0.4 month, and since there are 12 months in a year, the total number of tool changes for this router bit is 30 times.

Therefore, cash flows are expected as illustrated in the cash flow diagram below.



Excluding the initial cost, equal payments of $243.00 are expected for 30 times over the 12-month period. The NPV of the cash flows above can be calculated with an assumption of an interest rate also known as a discount rate.

According to interview with Tom Lewis (personal communication, April 1, 2011), a small business advisor at one of TD Canada Trust branches, the minimum loan amount through a business account is $10,000. There are two types of interest rates for business loans used to acquire business assets including machinery and equipment. The first type of interest rate is called the float interest rate, at which the interest rate can fluctuate during the loan period depending on the prime rate. Float interest rates equal the sum of prime rate and additional 4.25%. Since the current prime rate is 3.00%, the float interest rate for this type of business loan is 7.25%. Another type of interest rate is known as the fixed interest rate, at which the interest rate does not change over the loan period. However, greater interest rates are applied for longer loan-terms due to the increase in uncertainty in accounts receivable. For the same type of business loan, the fixed interest rate starts at 6.25% for a 1-year period, 7.00% for a 2-year period, and increases to 7.50% for 3-year period. Assuming that Platinum Millwork can pay off $10,000 in a year, the interest rate for this CBA will be 6.25%, which will also act as the minimum acceptable rate of return (MARR). This means that as long as the rate of return from an investment is greater than the MARR, that investment is acceptable (T. Sowlati, 2010).

In order to calculate the NPV, financial calculations will be used to compute the equivalent interest rate for each payment period (replacement period of router bit) as well as the discounted present value of all of equal payments of $243.

The formula for equivalent interest rate is as follows: $(1 + r_p)^p = (1 + r_c)^c$ (R. Mackinnon, 2011), where r_p is the interest rate for payment period, p for number of payment periods per year, r_c for interest rate for compounding period, and c for number of compounding periods per year.

Since the annual interest rate compounded yearly is 6.25% and there are 30 payment periods, r_p can be solved as calculated below.

$$r_p = (1 + 0.0625)^{1}\ 30 - 1;\ r_p = 0.00202\ or\ 0.202\%$$

The ordinary simple annuity formula is expressed as follows: $\mathrm{PV} = \mathrm{C}\ \frac{1-(1+r)^{-t}}{r}$ (R. Mackinnon, 2011). In this formula, PV is the discounted present value of all periodic payments at the end of each period, r for the periodic interest rate, and t for the number of periods.

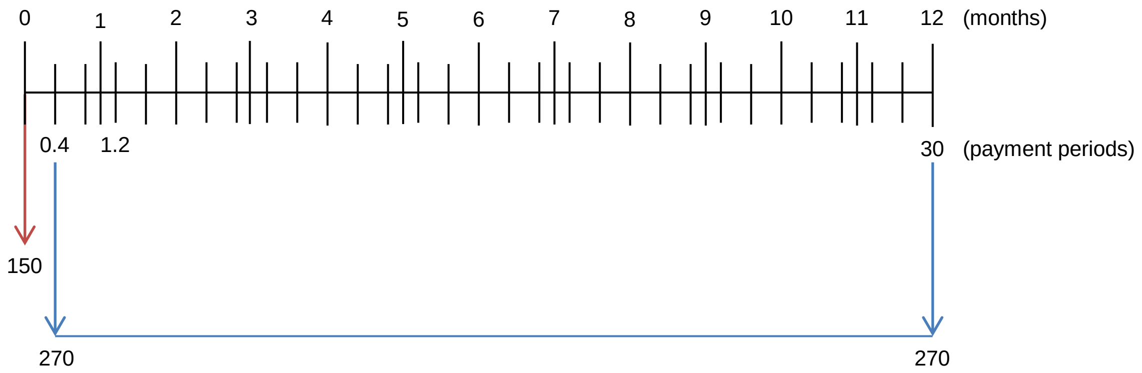
In this calculation, r will equal r_p and t will equal p while C = $243. PV can be solved as calculated below.

$$243\ \frac{1 - (1 + 0.00202)^{-30}}{0.00202} = 7{,}066.59$$

Therefore, adjusted by time value of money, the discounted present value of the periodic payments is $-7,066.59. Notice that the sign is negative since this is the present value of a cost. The NPV of Vortex 3289 VIPER is the sum of initial cost, -$243.00, and $-7,066.59. Hence, NPV = -$243.00 + -$7,066.59 = -$7,309.59 over a 1-year period.

Vortex VIPER+ 3289c

Repeating the same process for calculating the NPV of Vortex 3289 VIPER, consider the following cash flow diagrams as well as calculations.



The NPV of Vortex VIPER+ 3289c:

$$\text{NPV} = 270\ \frac{1-(1+0.00202)^{-30}}{0.00202} + 150 = 7{,}851.76 + 150 = 8{,}001.76$$

Therefore, the NPV of Vortex VIPER+ 3289c is -$8,001.76.

<u>Royce DIA-HIFEED.06</u>

The expected cash flows of the diamond router bit will differ greatly from that of carbide router bits. Under minimum conditions, the life expectancy of Royce DIA-HIFEED.06 is 30 times longer than that of either one of Vortex 3289 series. Since the tool life of carbide router bits is 0.4 month, the tool life of this diamond router bit is at least 12 months (0.4 x 30 = 12). The expected number of maintenance periods is 5 times during the diamond bit's tool life. This means that the diamond bit is taken under maintenance every two months. While carbide router bits were replaced 30 periods in annual terms, the diamond bit seems to be saving an abundant amount of cost since only one replacement is required over a 1-year period. Consider the following cash flow diagrams and calculations to see the difference in the NPV.

Since the number of payment period has changed, a new equivalent interest rate has to be determined. The calculation is illustrated as follows:

$$r_p = (1 + 0.0625)^{\frac{1}{5}} - 1;\ r_p = 0.0122\ or\ 1.22\%$$

The formula for computing the discounted present value of the future value is expressed as follows: $\mathrm{PV} = \frac{FV}{(1+r)^t}$ (R. Mackinnon, 2011); in this formula, FV is the future value, r for interest rate, and t for number of periods.

Hence, the NPV of the cash flows above is calculated below:

$$\mathrm{NPV} = 687.31 + 240\ \frac{1-(1+0.0122)^{-5}}{0.0122} + \frac{687.31}{(1+0.0625)^{1}} = 687.31 + 1{,}157.30 + 646.88$$
$$= 2{,}491.49$$

There for the NPV of Royce DIA-HIFEED.06 is -$2,491.49.

The total cost of two carbide router bits over a 1-year period is:

$$NPV_{Carbide1,2} = -\$7{,}309.59\ +\ -\$8{,}001.76 = -\$15{,}311.35$$

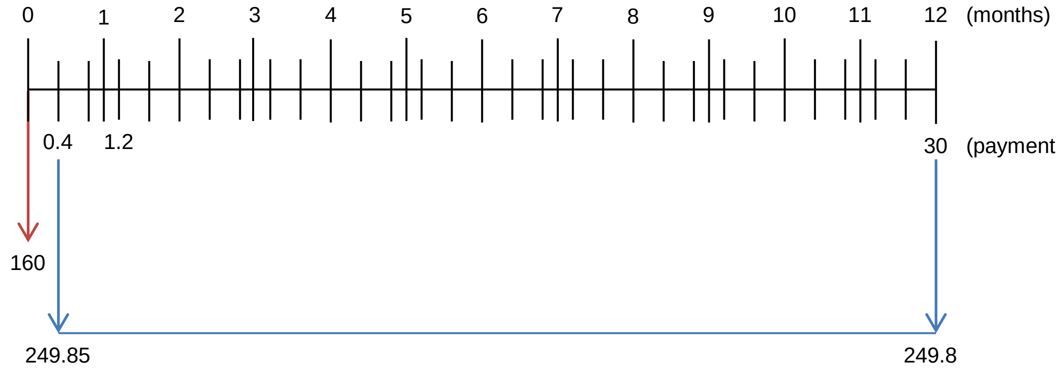
Therefore, the total cost saving from using the diamond router bit is the difference between the total NPV of two carbide router bits and the NPV of Royce diamond bit.

$$\text{Total Cost Saving} = \$15{,}311.35 - \$2{,}491.49 = \$12{,}819.86$$

In result, Platinum will save a total cost of $12,819.86.

<u>Vortex 4400 Three Flute Low Helix Up-cut Finisher</u>

Repeating the same process for calculating the NPV of Vortex 3289 series, consider the following cash flow diagrams and calculations.



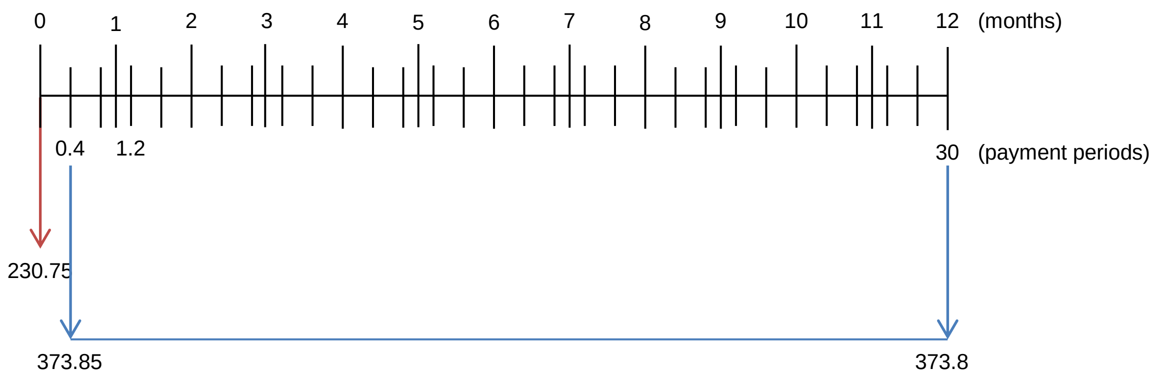
The NPV of Vortex 4400 Finisher:

$$\text{NPV} = 249.85\,\frac{1-(1+0.00202)^{-30}}{0.00202} + 160 = 7{,}265.79 + 160 = 7{,}425.79$$

Therefore, the NPV of the net cost over a 1-year period is -$7,425.79.

Vortex 4400 Three Flute Low Helix Up-cut Finisher (larger diameter)

Repeating the same process as above, consider the following cash flows diagrams and calculations.



NPV calculation:

$$\mathrm{NPV} = 373.85\,\frac{1-(1+0.00202)^{-30}}{0.00202} + 230.75 = 10{,}871.78 + 230.75 = 11{,}102.53$$

Therefore, the NPV of larger bit-diameter Vortex 4400 series is -$11,102.53.

Royce Custom Bit

Repeating the same process as that of Royce DIA-HIFEED.06, consider the following cash flow diagram as well as calculations.

NPV of net costs over a 1-year period is expressed as follows:

$$\text{NPV} = 1{,}116.64 + 375\,\frac{1-(1+0.0122)^{-5}}{0.0122} + \frac{1{,}116.64}{(1+0.0625)^{1}}$$
$$= 1{,}116.64 + 1{,}808.28 + 1{,}050.95 = 3{,}975.87$$

Therefore, the NPV of using Royce Custom Bit over a year is -$3,975.87.

The total cost of using carbide router bits for solid surfacing is calculated in the following calculation:

$$NPV_{Carbide3,4} = -\$7{,}425.79\ +\ -\$11{,}102.53 = -\$18{,}528.32$$

Therefore, the total cost saving for replacing the carbide router bits with the Royce Custom Bit is:

$$\text{Total Cost Saving} = \$18{,}528.32 - \$3{,}975.87 = \$14{,}552.45$$

Therefore, the total cost saving amounts to $14,552.45.

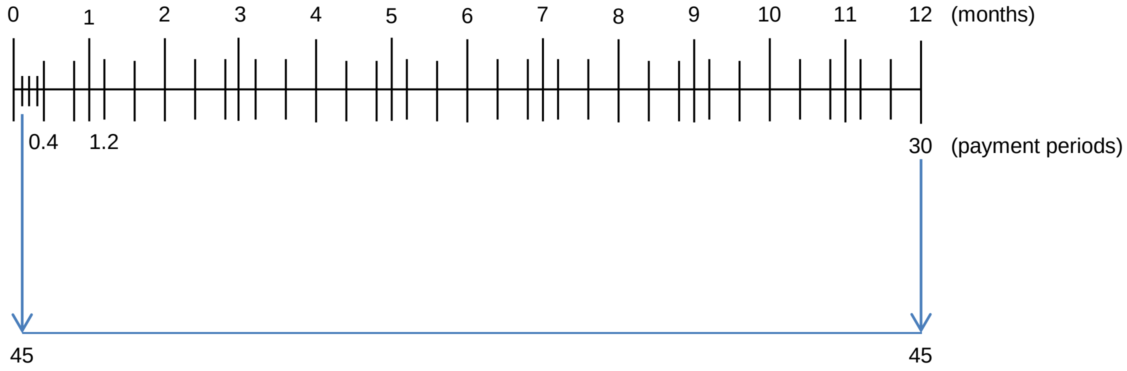
In result, the total cost of using all four carbide router bits and two diamond bits are illustrated below:

$$Total\ Cost_{Carbide} = \quad NPV_{Carbide1,2} + \quad NPV_{Carbide3,4} = -\$15{,}311.35 + -\$18{,}528.32$$
$$= -\$33{,}839.67$$

$$Total\ Cost_{Diamond} = -\$2{,}491.49 + -\$3{,}975.87 = -\$6{,}467.36$$

As the end of the cost analysis, Platinum Millwork will save total annual cost of $\$33{,}839.67 - \$6{,}467.36 = \$27{,}372.31$ by using the diamond-tipped router bits.

Consider the following cash flow diagram if Platinum's overhead cost is $90 per hour and each tool change takes 0.5 hours. Cash flows below can be expected as overhead costs due to so many tool changes for carbide router bits. Since a tool change is required for each maintenance period, and there are three maintenance periods in one replacement period for carbide router bits, the total number of tool changes required is 120 times (4 tool changes within 1 replacement period x 30 times). The tool is assumed to be already set-up on the first day.



Since the number of payments has changed, the equivalent interest rate will change accordingly as follows:

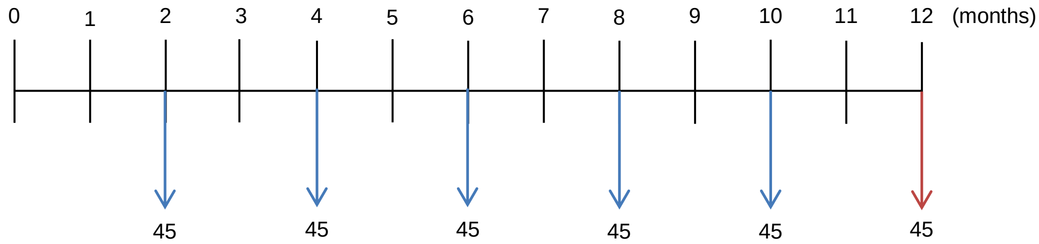
$$r_p = (1 + 0.0625)^{1/120} - 1;\ r_p = 0.0005053\ or\ 0.05053\%$$

The NPV of the cash flows above is calculated as follows:

$$\text{NPV} = 45\ \frac{1 - (1 + 0.0005053)^{-120}}{0.0005053} = 5{,}238.26$$

Therefore, a total of -$5,238.26 has resulted as loss in overhead cost. The total loss in overhead cost of -$5,238.26 will be added to the net cost of using the carbide router bits.

Diamond router bits would require less number of tool changes, at which creates smaller loss in the overhead cost as illustrated in the cash flow diagram below:



NPV calculation of the cash flows above:

$$\mathrm{NPV} = 45\,\frac{1-(1+0.0122)^{-5}}{0.0122} + \frac{45}{(1+0.0625)^{1}} = 216.99 + 42.35 = 259.34$$

Thus, the monetary benefit of savings in overhead cost by changing from carbide to diamond router bits is:

$$\text{Present Value of Benefits in Overhead Cost} = \$5{,}238.26 - \$259.34 = \$4{,}978.92$$

To measure the total loss in productivity due to tool changes, a comparison based on the feed rates of Vortex 3289 VIPER and Royce DIA-HIFEED.06 will be used to assess the benefits in money terms.

The total annual loss in productivity due to Vortex 3289 is:

$$\text{Productivity Loss}\ \ \text{in inches} = \frac{1{,}000''}{min} \times \frac{60min}{hr} \times 0.5hr \times 120\ \ \#\,of\ tool\ changes$$
$$= 3{,}600{,}000''$$

Therefore, 3,600,000 inches of stock could have been machined in production over a year.

The total annual loss in productivity due to Royce DIA-HIFEED is:

$$\text{Productivity Loss}\ \ \text{in inches} = \frac{800''}{min} \times \frac{60min}{hr} \times 0.5hr \times 6\ \ \#\,of\ tool\ changes\ \ = 144{,}000''$$

Compared to the productivity loss from Vortex carbide router bit, the annual loss in productivity due to Royce diamond bit is only 144,000 inches of stock.
In order to monetize the values above, Platinum's average job specifications will assume to be used as a common basis for comparing both productivity losses.
Platinum's average job requires approximately 120 hours, and is sold for \$20,000. The total CNC machining time in contribution to this job was 8 hours, at which the productivity of CNC machining in this job can be calculated as below:

$$\frac{1{,}000"}{min} \times \frac{60min}{hr} \times 8hr = 480{,}000"$$

In percentage, CNC machining contributed for 6.67% (8 hours / 120 hours) of the entire job. The money value generated from CNC machining in production is $1,334 (6.67% x $20,000). Therefore, the dollar per production value in CNC machining can be solved as follows:

$$\frac{\$1{,}334}{480{,}000"} = \$0.00278\ per\ inch$$

Assuming that $0.00278 per inch is an average monetary production value for Vortex 3289, the total monetary value in productivity loss would be:

$$3{,}600{,}000" \times \frac{\$0.00278}{"} = \$10{,}008$$

The above calculation means that $10,008 worth of productivity would be lost by the end of the year, and the present value of this monetized productivity loss would be added to the net cost of carbide router bits.

$$\mathrm{PV_{ProductivityLoss}} = \frac{10{,}008}{(1 + 0.0625)^1} = 9{,}419.29$$

For Royce DIA-HIFEED, the total monetary value in productivity loss would be:

$$\frac{800"}{min} \times \frac{60min}{hr} \times 8hr = 384{,}000";\ \frac{\$1{,}334}{384{,}000"} = \$0.00347\ per\ inc;\ \ 144{,}000" \times \frac{\$0.00347}{"} = \$499.68$$

The PV of the monetized productivity loss of the PCD router bit:

$$\mathrm{PV_{ProductivityLoss}} = \frac{499.68}{(1 + 0.0625)^1} = 470.2871$$

In consequence, the benefit of using Royce DIA-HIFEED, in monetary terms, is:

$$\text{Benefit at the End of the Year} = \$10{,}008 - \$499.68 = \$9{,}508.32$$

Since $9,508.32 is the future value of benefit in using diamond router bits, the present value is computed as illustrated below.

$$\mathrm{PV_{Benefits}} = \frac{9{,}508.32}{(1 + 0.0625)^1} = 8{,}949.01$$

This means that $8,949.01 worth of productivity can be recovered by using the diamond router bits mainly because of less number of tool changes.

Now that the net costs and benefits for both carbide router bits and diamond router bits have been determined, it is time to compare the BCR and NPV of the two alternatives.

Carbide Router Bits

$$\text{Benefits} = \$0$$

$$\text{Costs} = \text{NPV}_{\text{Carbide1+2}} + \text{NPV}_{\text{Carbide3+4}} + \text{NPV}_{\text{OverheadCost}} + \text{NPV}_{\text{ProductivityLoss}}$$
$$= -\$15{,}311.35 + -\$18{,}528.32 + -\$5{,}238.26 + -\$9{,}419.29 = -\$48{,}497.22$$

Since this case study was using carbide router bits as a base in comparison to an alternative tooling solution, there are no benefits in using carbide router bits at least not in terms of monetary value.

Diamond Router Bits

$$\text{Benefits} = \text{NPV}_{\text{BenefitsinOverheadCost}} + \text{NPV}_{\text{BenefitsinProductivityIncrease}}$$
$$= \$4{,}978.92 + \$8{,}949.01 = \$13{,}927.93$$

$$\text{Costs} = \text{NPV}_{\text{Diamond1}} + \text{NPV}_{\text{Diamond2}} = -\$2{,}491.49 + -\$3{,}975.87 = -\$6{,}467.36$$

$$\text{BCR} = \frac{\text{Benefits}}{\text{Costs}} = \frac{13{,}927.93}{6{,}467.36} = 2.15$$

$$\text{NPV} = \text{Benefits} - \text{Costs} = \$13{,}927.93 - \$6{,}467.36 = \$7{,}460.57$$

Appendix C

The below figures are CAD of Royce DIA-HIFEED.06.

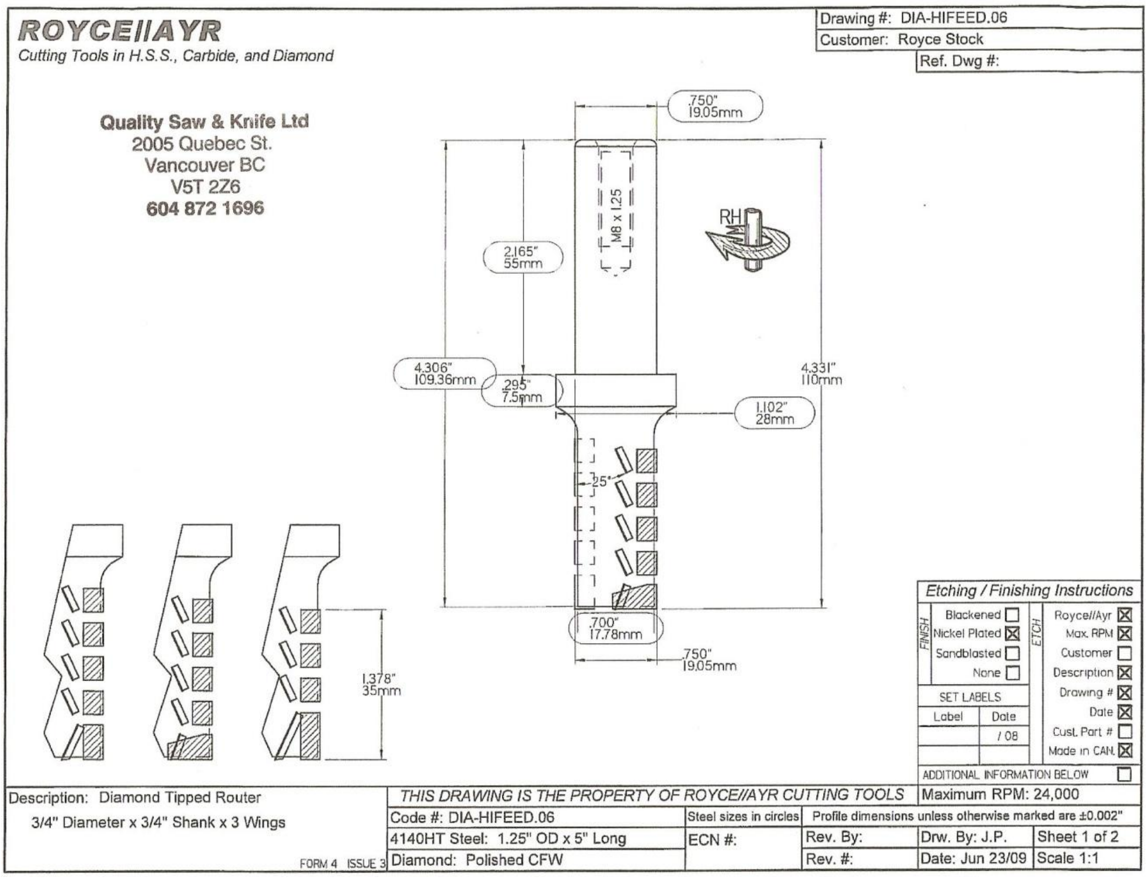


Figure 12. CAD Drawing of Royce DIA-HIFEED.06 (Quality Saw & Knife, 2011)

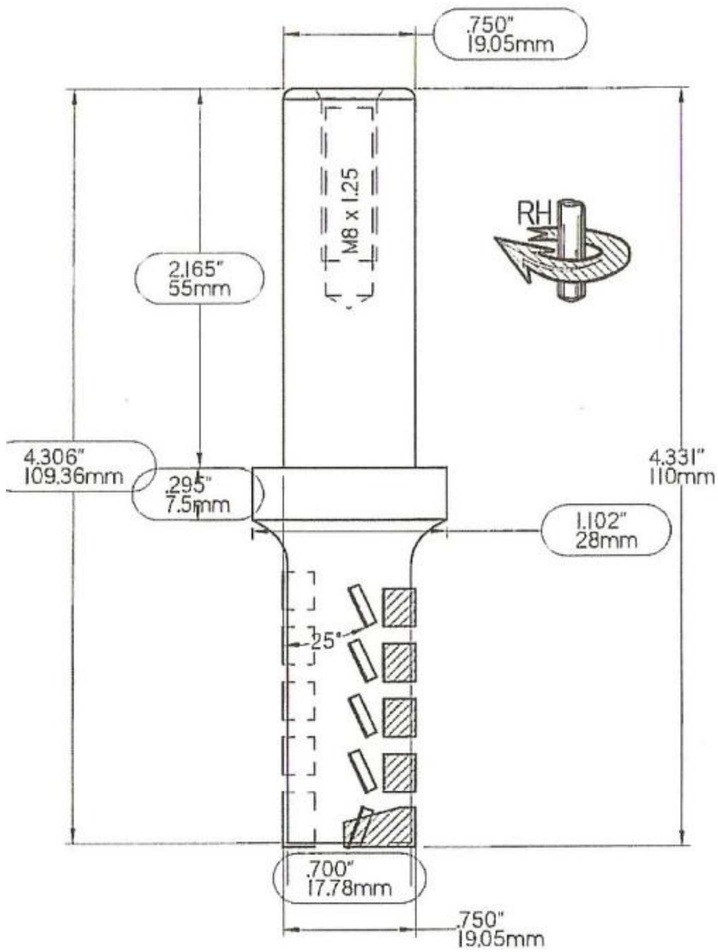


Figure 13. Royce DIA-HIFEED Full Front View (Quality Saw & Knife, 2011)

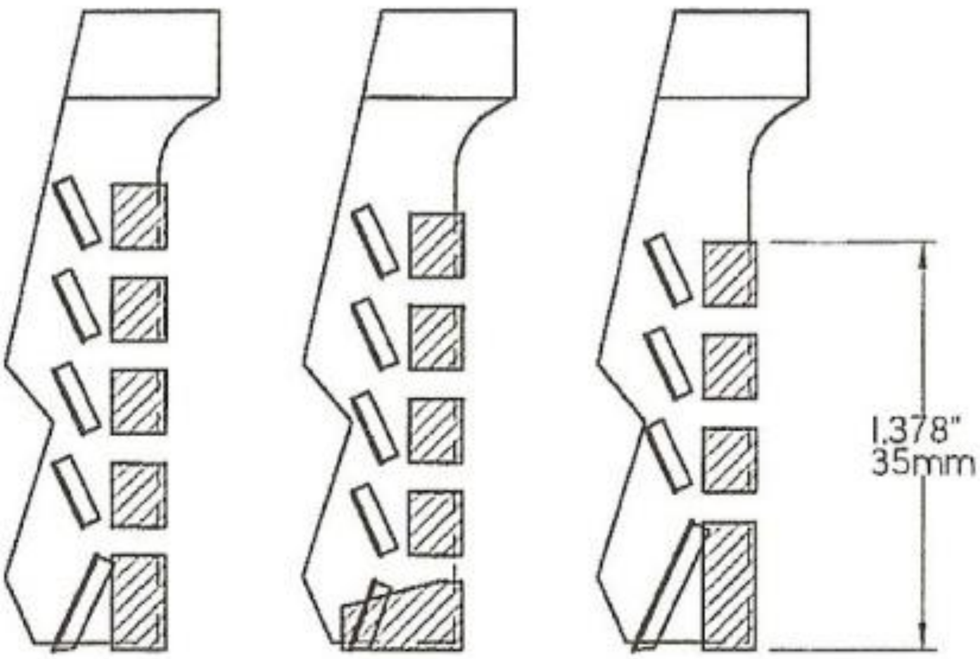


Figure 14. Royce DIA-HIFEED from Side View (Quality Saw & Knife, 2011)

The actual photo of the same diamond router bit found from Royce's precision CNC tooling catalogue is shown in the figure below.

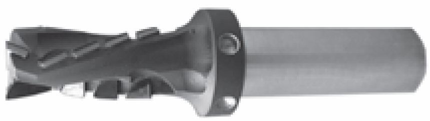


Figure 15. Actual Photo of Royce DIA-HIFEED.06 (Royce//Ayr Cutting Tools, 2010)