Determining the Economics of New Moulder Configurations

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Abstract

The moulder is one of the most widely used machines in the wood industry. Its function is to cut stock with rough dimensions to a finished width, thickness, and cross-sectional shape in one pass, making it cost effective to produce mouldings, floors, window and furniture components, etc. Today's moulders are fast, safe, flexible, versatile, precise, and productive. Many different configurations can be selected when specifying the purchase of a moulder. The Moulder Economic Calculator (MEC) was developed to determine the economic impact of choosing different moulder configurations. The calculator uses input data on machine price and purchase method, machine configuration, production parameters, and production costs. The MEC program gives three types of outputs: surface quality, productivity, and costs. The MEC program is a flexible tool that allows the user to estimate the cost of machining one linear foot of wood. Some capabilities of the MEC program include determining the effect of machine price on machining cost, the effect of setup time on production time, and the effect of machine configuration on machining cost. In this way, the MEC program allows the user to compare between different machine configurations and determine which best meets the user's cost, production, or flexibility requirements. The model was taken to Weinig USA, where their experts reviewed the model and offered their input.

The purpose of the moulder is to cut stock that comes with rough dimensions from the rough mill to a finished width, a finished thickness, and a finished cross-sectional shape in one pass (Clark et al. 1987). A moulder consists of a heavy, one-piece, iron frame with table plates on top and motors that drive the spindles on which cutter heads are mounted (Weinig USA 2005). The first horizontal spindle and the first vertical spindle produce two reference planes 90 degrees from which subsequent moulding cuts can be accurately measured and controlled (Clark et al. 1987). The ability to process all four sides of a piece of wood at the same time makes it cost effective to produce mouldings, flooring, door and window components, furniture, and more (Hassel 2000), making the moulder one of the most widely used machines in the wood industry.

Machine manufacturers have developed faster moulders to produce higher volumes. They have introduced more spindles and spindle arrangements for specific products and qualities. They have modified the feed system to handle shorter, out-of-square end and warped pieces. Tool clamping systems have been modified to improve precision. Safety features, such as safety hoods linked to power switches that will shut off the machine when the operator opens the hood, have been incorporated to make moulders safer machines (Derning 1995). Until recently, the major focus of research and development has been on quicker setup and increased productivity (Anonymous 1992).

As customers demand consistent quality, smaller batches, more variety of products, shorter lead times, and customized items (Weinig USA 2005), more manufacturers are moving toward ''just-in-time manufacturing'' to keep inventory down and produce only what is needed, which implies more setups in a given day. With more setups, the machine is down (unproductive) a higher percentage of the time. In response, faster setup systems are being developed, such as

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the use of Computer Numerical Control (CNC) to adjust spindles and the recent introduction of the hollow-taper-shank (HSK) tool clamping system for quicker changeover and better surface quality at faster feed rates (Ponsolle 2002).

Over the past two decades, greater emphasis has been placed on developing ''smarter'' moulders through advances in computer control systems (Anonymous 1992). In addition to adjusting to the next required position, moulders with CNC controls also are capable of providing an increased amount of information to operators. Thus, the machines can generate important information to be used as a method of production management. Molder computers can keep track what job is being run, how many board feet (linear feet) are being produced, and who is operating the machine and when they take breaks, helping to uncover production-related problems (Derning 1995).

As a result, the woodworker is faced with many different machine choices that can vary greatly in price. According to its configuration, specifications, brand, and country of origin, the price of a moulder can range from $15,000 to upwards of half a million dollars. The proper selection of features and the technical and economic impact of the selection can be intimidating. Tooling and moulder manufacturers describe the cost and benefits of the new innovations of their product line. What is not always available is a clear understanding of the overall economic and productivity implications of implementing one or more of these new design features. The productivity of the machining process also needs to be taken into account.

Koch (1985) described the productivity of a moulder by the following equation:

$$P = V(60T - CX)(Y)(K)$$

where

P = linear footage of mouldings produced per shift,
V = feed speed (ft per min),
T = length of shift (h),
C = idle machine time due to each pattern change (min),
X = number of pattern changes per shift,
Y = pattern multiples, and
K = continuity of feed (% efficiency expressed as a decimal fraction).

This factor (P) must include all nonmachining time due to all causes other than pattern change.

According to Ratnasingam et al. (1999), productivity in wood machining processes has two essential dimensions: the resultant surface quality and the cost incurred in producing the surface. Ratnasingam et al. (1999) also point out that machining-related cost can account for 23 percent of the total production cost. However, one of the failings of the current costing system for products in the furniture industry is the treatment of machining cost as an indirect cost, usually calculated as a percentage of direct labor costs. This practice does not provide the necessary information to measure the productivity of the process. Ratnasingam (2002) calculates the machining cost as the total sum of the tooling cost, machine hours, labor hours (including setup time), and power consumption.

Annamalai (2003) at North Carolina State University developed a software tool called the Router Economic Calculator (REC) program to evaluate the economical implications of investing in high-speed/high-power CNC router technology. This program permits the user to change the different costs involved in the production of a product based on the particular situation of the industry and generate a final cost of the product. The REC is a useful decision-making tool to help router manufacturers and users improve their processes.

The purpose of this project is to provide the US woodworking industry with an economic calculator based on useful information on the technical and economic aspects of the modern moulder that will help the user determine the economic impact of choosing different moulder configurations. The calculator developed for this project is similar to the REC except that it has been specialized for the feeds, configurations, and through-puts of moulders instead of routers. In addition to the software program, another objective of this project was to illustrate the parameters that a wood manufacturer must take into account when calculating the cost of buying or using a moulder.

Methodology

The basic goal of the Moulder Economic Calculator (MEC) program is to translate machine features in a simple and objective manner into production capabilities and cost of operation. The MEC program uses LabVIEW software for input and output data and requires a basic knowledge of the machine capabilities and of the production requirements. It is based on economic considerations of the wood machining process. It allows the user to compare different types of moulder configurations. The steps taken in creating the program included examination of the technical and economic aspects of the moulder, consultation with machine experts, consultation with moulder users, determination of inputs and outputs of the program, development of a PC-based model with LabVIEW software, and validation of the model with experts (Weinig USA) and users.

Description of the MEC Program

MEC program inputs

Default values are expert-provided typical values that are presented for every input. The user can input his or her own operation-specific values via the input boxes. The input screen entry options include several configuration settings related to machine price, machine configuration, machine setup, production rates, and production costs.

Machine price.—This is the purchase price in US dollars. The user needs to indicate if the machine is being leased or purchased. When leasing, the user has to enter the lease rate and the lease period. When buying the machine instead of leasing it, the user needs to indicate the type of depreciation.

Machine configuration.—There are 17 entry options related to moulder configuration and setup. A brief description of each is provided.

- Changeover time: The time it takes to make a changeover for a new job/profile. Choosing this option will ignore other setup time–related input options (e.g., spindle and tool setup times). However, if the user does not know the setup time, he or she can rely on the program to calculate it.
- Number of spindles: Moulders are modular, meaning that the purchaser can specify a number of different spindle

arrangements. The first module always consists of the facing operation, followed by the jointing to 90 degrees (Clark et al. 1987). Additional spindles help remove more material with lower load on each motor (V. Cortes, Weinig USA, personal communication, 2006). The total number of spindles in the machine normally ranges from 4 to 12.

- Adjustable spindles: This is the number of spindles that are adjusted on average every time there is a changeover.
- Feed rate: The speed at which the workpieces are run through the machine. The range is from 0 to 500 feet per minute.
- Spindle speed: Moulders use belt-drives with three-phase asynchronous (AC) motors in the power range of 5 to 50 hp. Depending on the belt drive transmission and the motor speed, different revolutions per minute (rpm) for the spindles can result according to H. Klein (Michael Weinig AG) and B. Koenigsfeld (SK USA, Inc.) (personal communication, 2006). Today, machine manufacturers offer standard 6,000-rpm spindles, and some have moulders with spindles that run at 8,000 and 8,300 rpm. The recent adoption of the HSK tool clamping system allows speeds up to 12,000 rpm.
- Spindle positioning indicators: There are three choices: mechanical, electronic, and computer controlled (CNC).
- Spindle setup time: This is the time that it takes the operator to position one spindle, including its pressure shoe and chip breaker. The program has predetermined spindle setup times for each type of indicator: 5 minutes for mechanical, 4 minutes for electronic, and 1.5 minutes for CNC.
- Tool clamping system: Clamping systems are the means to hold and drive the cutter heads with motors or machine spindles (Effner 1992). The user can choose between conventional, hydro, and hollow-taper-shank (HSK; Lewis 1999, Destefani 2002).
- Tool setup time: This is the time it takes the operator to mount a tool on the machine. The program has predetermined tool setup times for each system: 2 minutes for conventional, 3 minutes for hydro, and 0.25 minutes for HSK.
- Jointers: To remedy uneven knife marks or a single knife finish caused by poor static concentricity, the knives on the cutter head are sometimes honed while rotating at operational or slower speed in a process called jointing, ensuring that all the knives are on the same cutting circle. This input asks for the presence of jointers. If the answer is no, the program assumes only one knife finish for the surface quality. If the answer is yes, the program uses the total number of knives per tool to determine the surface quality.
  - Number: Refers to the number of spindles that have jointers. This number needs to be greater than zero if the user indicated that there were jointers in the machine.
  - Type: There are two choices: traditional or older-type jointers that need to be assembled on the machine and cassette jointers that can be preassembled and then mounted on the machine.
  - Jointer setup time: This is the time it takes to change each jointer for a new profile. Traditional jointers are assigned a default setup time of 30 minutes per jointer. The default time for the cassette type system is 3 minutes per jointer.
- Feed system: This input option allows the user to indicate if the price and horsepower of the feed system should be added to the machine price and horsepower. It also allows specification of the number of moulder operators; it is preferable to reduce the number of operators to one.
- Horsepower: Total horsepower of the machine, including the spindle motors and the feed motor.
- Tool diameter: Refers to the outer diameter of the cutter head in inches; used to determine the surface quality.
- Number of knives per tool: This is the number of knives mounted on the cutter head, and it is used to determine the surface quality.

Production parameters.—There are five entry options related to production parameters.

- Shift length: The default value is an 8-hour shift, as is typical in the industry.
- Number of shifts per year: This refers to the approximate number of shifts the machine will be operated over the course of a 1-year period. It is used to calculate the machining cost per shift (based on typical yearly lease rate).
- Number of operators: This refers to the number of operators required to run the machine on a regular basis during a single shift. This does not include setup personnel. The default value is set at two, one operator for feeding the machine and the other one for tailing the machine. This needs to be changed when using feed systems.
- Jobs: This is the number of different orders or profiles that are usually produced per shift. Each job would require a setup of spindles and tools.
- Production: Refers to the actual production or linear footage that the user is currently producing or desires to produce during one shift.

Production costs.—There are four entry options related to production parameters.

- Operator cost: The operator cost is more than the wage paid per hour; it should also include the costs of overhead and liability.
- Maintenance cost: This refers to the cost incurred per shift to maintain the machine, including maintenance personnel, repairs, spare parts, etc.
- Power price: This is the price in dollars per kilowatt-hour and depends on whether the user produces one's own power and, if not, the price determined by the agreement the user has with the power company.
- Tooling expenses: Refers to the total cost of tooling for the machine incurred during 1 year and varies according to total production, feed speed, spindle speed, workpiece material, and cutting material.

MEC program outputs

Surface quality outputs.—Two surface quality outputs are provided: knife marks per inch and pitch height. Knife marks are the series of ridges produced when machining with a rotary cutter, and the frequency of knife marks determines the surface finish. Pitch height is the depth to which the cutting knives enter the wood. The workpiece surface is better the smaller the pitch height.

Productivity outputs.—Four productivity outputs are provided: changeover time, setup time, possible jobs, and production time. Changeover time is the time it takes to change the tools, reposition the spindles, rearrange the pressure elements, and change the jointers to prepare the machine to run a new profile as calculated by the program or as entered by the user in the setup time input. Total setup time is the total time spent in one shift doing setups. An error message is given to the user when the setup time is greater than the available time (length of shift minus idle time). Possible jobs is the maximum number of jobs or changeovers that can be made with the given configuration and production parameters to meet the desired production, utilizing the total shift length. Finally, production time indicates how long it will take to meet the actual or desired production with the given number of jobs. It is a function of the production, the feed speed, and the total setup time.

Cost outputs.—There are nine entry options related to cost.

- Machine cost: This is the cost of having the machine. When the machine is leased, it is the cost of leasing at a given rate of the dollar value. When the machine is purchased, it is the cost born for the depreciation of the machine.
- Setup cost: The setup cost is calculated from the setup time and the machine cost per shift and is the cost incurred for having the machine not running during the production time.
- Labor cost: This is the cost of having operators running the machine for the production time. The shorter the production time, the lower the labor cost because the operators can work on other machines or processes in the plant.
- Tooling cost: The tooling cost is simply the average tool expense per shift.
- Power cost: This refers to the electrical power cost incurred during one shift of operating the moulder. A generic equation for power consumption based on total horsepower, power price, load, and efficiency is used in the MEC calculations. The load factor is the fraction of the motor's horsepower actually used to drive a load (Minnesota Technical Assistance Program [MNTAP] 2003). Motors rarely operate at their full-load point. Since the calculation is done for the total horsepower (sum of all motors), it is assumed that there is not a full load, and a value of 85 percent was chosen based on a worst-case scenario. A motor efficiency value of 83 percent was used following the examples of the MNTAP (2003) fact sheet.
- Maintenance cost: Average maintenance expense per shift.
- Total cost per shift: The sum of the machine, setup, tooling, power consumption, and maintenance costs per shift. A pie chart included as part of the output shows the distribution of the different costs.
- Total cost per year: Translates the total cost per shift into the total cost per year, which can be useful for financial decisions.
- Machining cost: This is the cost of machining one linear foot with the given machine price, configuration, production parameters, and costs.

Solution method

The MEC program is based on simple algebraic equations that relate the inputs to the outputs:

Knife Marks per Inch = 1/ft = 12 × Feed Rate/No. of Knives × RPM

Pitch Height = $\text{ft}^2/\{8 \times [\text{Tool Diameter} + (\text{ft} \times \text{No. of Knives}/\pi)]\}$

Total Setup Time = Setup Time × No. of Jobs per Shift

Setup Time = Total Tool Changeover Time + Total Spindle Positioning Time + Total Jointers Setup Time z

OR Setup Time = specific value entered by user

Total Tool Changeover Time = No. of Adjustable Spindles × Tool Changing Time

Total Spindle Positioning Time = No. of Adjustable Spindles × Spindle Positioning Time

Total Jointers Setup Time = Number × Jointers Setup Time

Possible Jobs = (Shift Length − Production/Feed Rate)/Setup Time

Production Time = (Production/Feed Rate) + Total Setup Time

Machine Cost per Shift for Leased Machine (MC) = Machine Price × Lease Rate × Lease Period/(Shifts per Year × Lease Period)

Machine Cost per Shift for Machine Depreciated with MACRC (MC) = Machine Price/(8 × Shifts per Year)

Machine Cost per Shift for Machine Depreciated at Market Value (MC) = (Machine Price − Machine Price × Resale Value/100)/(Useful Life × Shifts per Year)

Setup Cost (SC) = Machine Cost × Total Setup Time/Shift Length

Labor Cost (LC) = Number of Operators × Operator Cost × (Production Time/Shift Length)

Tooling Cost (TC) = Tooling Expenses/Shifts per Year

Power Consumption (PW) = Horsepower × 0.7457 × Shift Length × Power Price × Load Factor/Motor Efficiency

Maintenance Cost (MT) = Maintenance Expenses/Shifts per Year

Total Cost per Shift = (MC + SC + LC + TC + PW + MT)

Total Cost per Year = Total Cost per Shift × Shifts per Year

Machining Cost = (MC + SC + LC + TC + PW + MT)/Production

Results and Discussion

MEC program window

Figure 1 is a picture of the final window of the MEC program with the default values as explained in the previous section. The left side has the inputs and the right side the outputs.

MEC program examples

The MEC program allows the user to compare machines with different setup systems, feed rates, spindle speeds, and prices for the same production. Some examples of the capabilities of the MEC program are as follows.

Effect of machine price.—The sensitivity of machining cost to machine price was evaluated for a given set of

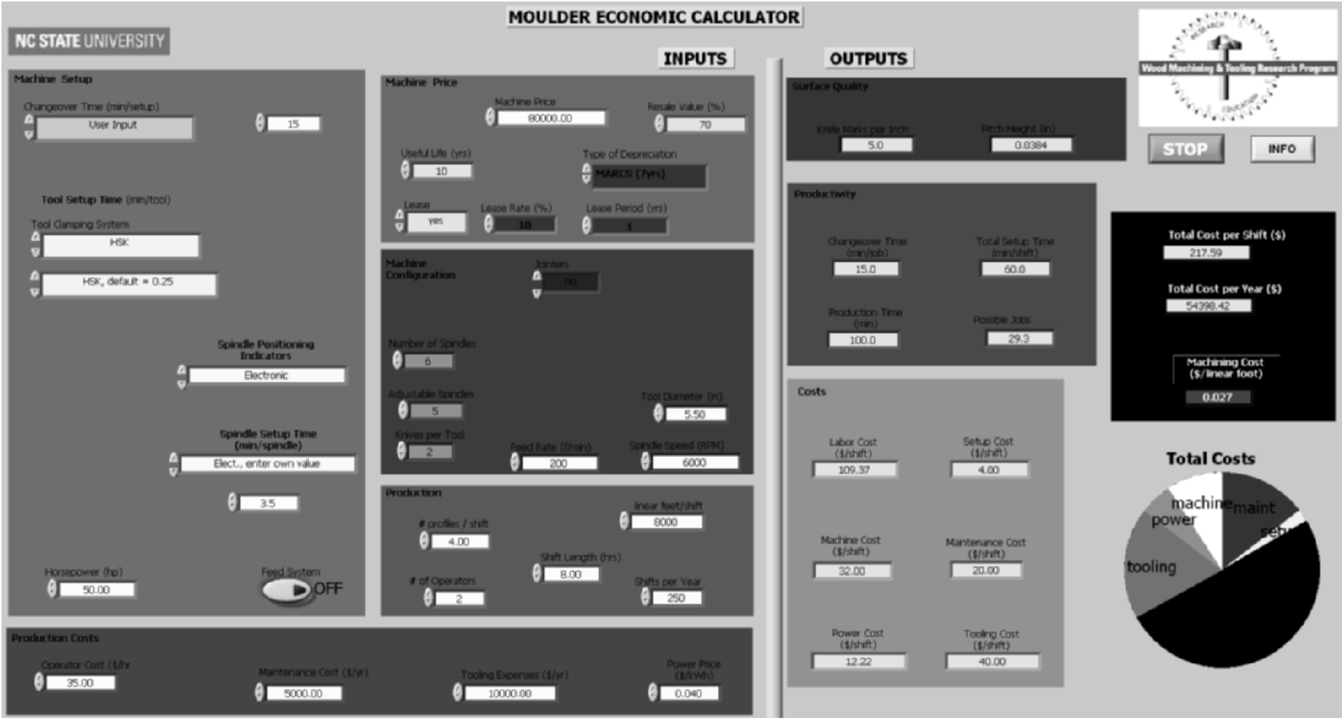

Figure 1.—MEC program window with default values.

conditions of machine configuration, production parameters, and production costs as given in Table 1. The results in Figure 2 show that machining cost remains constant within the evaluated price range for a given configuration. The figure also shows no difference between running 8,000 or 12,000 linear feet of material. Nevertheless, for smaller production runs, the machining cost is higher than for larger production runs. There is a $0.02 difference in machining cost, which amounts to a 40 percent cost difference between the 4,000- and 8,000 (12,000)-linear-feet production runs.

Table 1.—Conditions for analysis of machining cost.

Input parameter	Values used in examples
Machine price	
Machine price	$30,000–$100,000
Lease, lease rate, lease period	Yes, 10%, 1 y
Feed system	No
Machine configuration	
Changeover time, user's value entered	14 min
Number of spindles, adjustable spindles	5, 2
Horsepower	50 hp
Tool diameter, knives per tool	5.5 in., 2
Jointers	No
Feed rate, spindle speed	40 fpm, 6,000 rpm
Production parameters	
Shift length, number of shifts per year	8 h, 250
Number of operators	2
Jobs	4
Production	4,000, 8,000, and 12,000 lft
Production costs	
Operator wage	35 $/h
Maintenance cost	2,000 $/y
Power price	0.04 $/kWh
Tooling expenses	5,000 $/y

Effect of setup time.—Using the same inputs from Table 1, the effect of different setup times on the number of possible jobs for different feed rates was examined for a production run of 8,000 linear feet. The results given in Figure 3 show a negative power trend, with the number of possible jobs approaching zero as the changeover time increases. The impact of improvements in setup time on the number of possible jobs per shift is greatest in the range of 0 to 20 minutes per setup.

Logically, faster feed speeds also allow for higher numbers of setups—more than 200 jobs per shift are possible with a feed speed of 200 linear feet per minute compared with less than 50 at 20 linear feet per minute. Nevertheless, as the changeover time increases above 30 minutes, there is not much difference between faster and

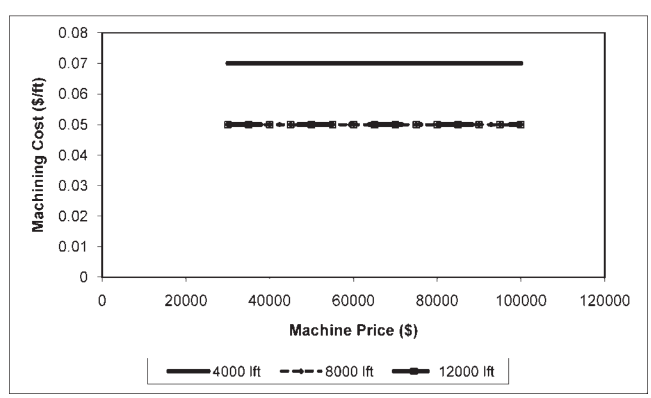

Figure 2.—Effect of machine price on machining cost for different levels of production.

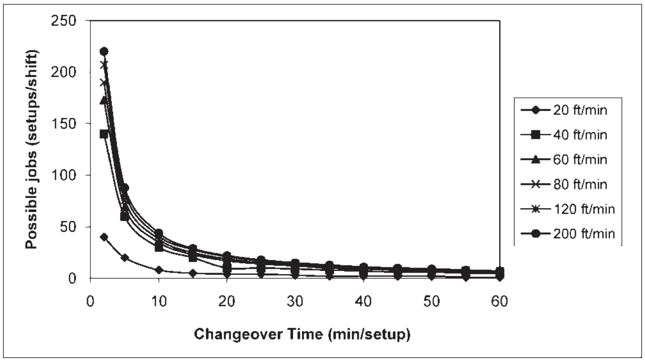

Figure 3.—Effect of changeover time on the possible jobs or setups per shift.

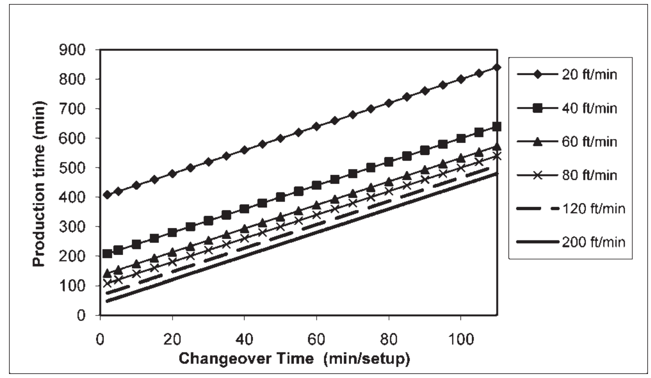

Figure 4.—Effect of changeover time on production time.

slower feed speeds. One must remember that faster feed speeds produce a lower surface quality at the same spindle speed. The effect of the changeover time on the number of jobs possible is important because companies aiming for just-in-time production need shorter setups in order to produce only the orders as they come in the system. Custom manufacturing also puts pressure on reducing the setup time since shorter setups allow for higher flexibility.

Figure 4 shows how the changeover time affects the total production time for different feed speeds. The intercept of the x-axis is set at 480 minutes to show where total setup time reaches the shift length. It can be seen that, as the changeover time increases, the production time increases linearly and that faster feed speeds allow the user to produce the same amount of linear feet in less time, though, as stated before, at the expense of the surface quality if the spindle speed is kept constant.

Effect of machine configuration.—Another example of the MEC program capabilities is the comparison of different machine configurations. The effect of six different machine configurations, shown in Table 2, on machining cost was examined. When comparing machines of different configurations, it is important to take into account that faster feed speeds mean faster wear of the tools, hence a higher tooling cost, and that machines with technologically advanced features such as CNC and HSK have a higher purchase price. In addition, machines with HSK are capable of producing the same amount of linear feet at the same surface quality in shorter time because they can run at faster rpm. Such considerations were taken into account in this example.

MEC program results show that even though moulders with HSK are more expensive, the total cost of operating the machine per shift is lower than for other configurations. This is due to the fact that they can reach the same production in less time because they can run at faster speeds and produce the same quality and because less time is spent in setup so that more time can be dedicated to run the machine. The reduction in production time results in lower labor cost because the operators can be moved to other machines or processes. The importance of this result is that it can translate into thousands of dollars saved per year.

Figure 5 presents the effect of machine configuration on machining cost (dollars per linear foot). The results parallel those for total cost per shift. Machines with HSK have a lower machining cost per linear foot than the other configurations. Although it seems that there are only a few cents' difference in machining cost between the different configurations, this difference can amount to as much as a 50 to 80 percent increase in the cost of a job.

It must be pointed out that the previous examples are based on the given conditions and the default values, which are based on assumptions. Results may vary for different production parameters and machine configurations. Other examples of using the MEC program are possible, such as comparing the machining cost with and without feed systems, comparing costs between leasing and purchasing the machines, etc.

Finally, it also has to be noted that the program does not take into account any options that may be added to the machine configuration in the future that may improve the operation, such as the grooved bed or the table plate for wood inserts.

Table 2.—Six different machine configurations for small production and few jobs.[a]

Parameter adjusted	Scenario 1 value	Scenario 2 value	Scenario 3 value	Scenario 4 value	Scenario 5 value	Scenario 6 value
Machine price ($)	80,000	100,000	170,000	150,000	170,000	190,000
Spindle positioning indicators	Mechanical	Electronic	Electronic	Mechanical	Electronic	CNC
Tool clamping system	Conventional	Conventional	Hydro	Hydro	HSK	HSK
Feed rate (fpm)	40	40	40	40	80	80
Spindle speed (rpm)	6,000	6,000	6,000	6,000	12,000	12,000
Maintenance cost ($/y)	5,000	5,000	6,000	6,000	5,000	5,000
Tooling expenses ($/y)	4,000	4,000	10,000	10,000	10,000	10,000

[a] Program constants: feed system, none; setup time, calculate; adjustable spindles, 3; horsepower, 50; spindle setup time, default; tool diameter, 5.5 inches; knives per tool, 2; jointers, none; shift length, 8 hours; number of shifts, 250; number of operators, 2; number of jobs, 8; production, 8,000 lf; operator wage, 35 $/h; power price, 0.04 $/kWh.

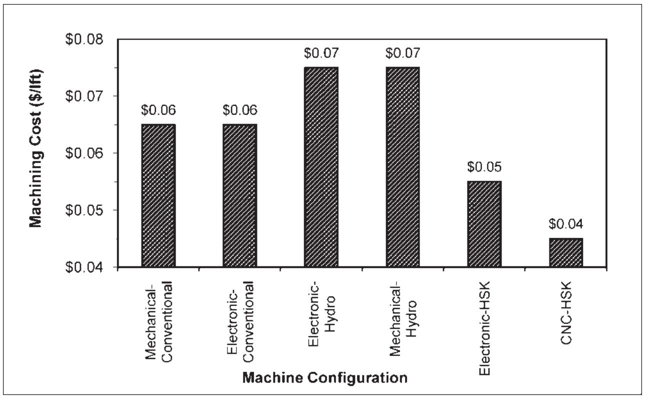

Figure 5.—Effect of machine configuration on machining cost.

Conclusions

The MEC program is a flexible tool that allows the user to determine the cost of machining one linear foot of wood with a particular machine configuration, production parameters, and production costs. It helps avoid mistakes by informing the user when a machine configuration is not adequate for a particular production and/or number of jobs. The program also allows the user to compare different machine configurations and determine which one is best based on cost, production, or flexibility. In comparing machine configurations, the user has to take into account differences in machine price, tooling cost, maintenance cost, feed speed, and spindle speed.

The MEC program shows that machine price is not the only variable that strongly influences machining cost and therefore should not be the only factor considered in purchasing a moulder.

Current limitations of the MEC program include the following: (1) it can analyze only one machine configuration at a time, so a user must keep track of configurations if comparing multiple setups; (2) it does not account for advantages from different spindle arrangements; and (3) it does not account for options that may be added, such as the grooved bed or the table plate for wood inserts.

The MEC program is an objective decision-making tool, but the woodworker also needs to consider other aspects that cannot be quantified, such as the after-sales service in terms of spare parts, maintenance, and repairs as well as the machine quality.

The MEC program is available free of charge and can be downloaded from the North Carolina State University Wood Machining and Tooling Research Program Web site at http://www.ncsu.edu/wmtrp.

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