Selecting High Tech Production Machines: A Guide for Entrepreneurs and Small Manufacturing Businesses

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This study presents a set of practical criteria and guidelines for small manufacturing business entrepreneurs who are looking for starting or growing a business through the addition of multifunctional computer numerical controlled (CNC) technology. This technology is capable of meeting several production goals including faster processing, minimizing non-value added times, concurrent processing of multiple parts and flexibility in processing high mix of products. A framework of technology selection and discussion of critical selection criteria is presented. Technical and cost data from several suppliers as well as practical examples are provided.

INTRODUCTION

The introduction of new technologies and innovations has made a new generation of multifunctional production machines (MPM) more responsive to market needs and variability. MPMs are computer numerical controlled (CNC) workcenters capable of performing a variety of operations with multiple tools and/or spindles in single setup. The advancement of computer technology and its application in the manufacturing industry has transformed these systems from stand-alone production units to complex integrated multifunctional workcenters. These systems can contribute to significant savings in manufacturing operations due to their ability to complete complex parts with a multitude of features and geometries without the need for multiple setups and inter-machine part transfers.

MPM is a crucial digital manufacturing technology for a range of industries, delivering fast turnaround of parts and prototypes. According to Baker and McInturff (2007), small manufacturing businesses with 50 or fewer employees constitute over three-fourths of all U.S. manufacturers. MPM equips these businesses and entrepreneurs with a flexible automation solution in responding to today's market fluctuating demand for one-of-a-kind and high-mix, low-volume products as the days of doing million-part production runs are few. The challenge today is for small manufacturing businesses to produce as many part design features as possible in a single setup on a single machine. Benefits of doing more with less include compressing lead times and reducing lot sizes as small as one piece (Park, 2012). As the demand are increasing for machining of parts with complex shapes, the MPM technology is advancing by increasing the number of simultaneous motion axes control (Moriwaki, 2008). These developments have made multifunctional production machines increasingly sophisticated and expensive capital equipment. Therefore, the selection of a system for the right application and at the right price is an important decision for a small manufacturing business entrepreneur in identifying the best resources that suit the business operation and ensure the efficiency of each resource employed.

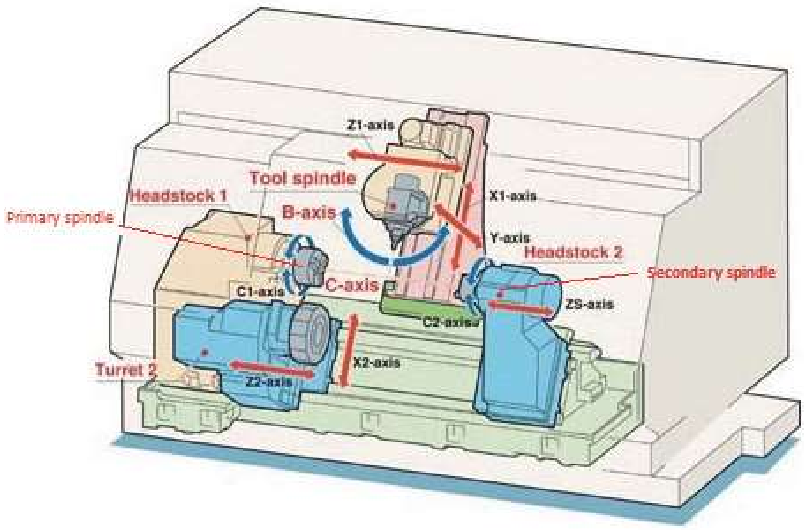
Limited guidelines on machine tool technology selection are at disposal of decision makers. Djassemi (2009) presented a review of basic and advanced features of MPMs and discussed several machine configurations. Arslan et.al. (2005) suggest a decision support system for machine tool selection by creating a sample database for a limited number of machine tools and applying a multi-criteria weighted average method to rank the alternatives. The database included information about machine type and size, spindle, tooling, work support, and axis of motion. The selection criteria consisted of precision, cost, reliability, safety, space, flexibility and productivity. The study of Selvaraj et.al. (2006) points to appropriateness of MPMs in the aerospace industry where the design of components changes frequently and there is a need for a machine that can adapt to each situation. These studies and similar ones are typically limited to general-purpose machine tool technology. However, the selection of multifunctional production machines is more complicated because it involves the selection of numerous complex configurations and advance features. This study provide a simple and practical guideline for small shop entrepreneurs entering crowded industrial marketplace in establishing or expanding a small manufacturing shop.

It is worth mentioning that multifunctional CNC machines are based on the concept of material subtraction. However, in recent decade an alternative concept known as additive manufacturing also refer to as 3D printing has emerged. It is agreed by many practitioners that 3D printing technology should be used to complement subtractive manufacturing rather replacing it. The former can be used for rapid prototyping, proof of concept, small size custom part with low production quantity while the latter is capable of mass production.

MULTIFUNCTIONAL ATTRIBUTES

A multifunctional production machine can be defined as a material removal technology that is capable of performing simultaneous and/or sequential operations on one machine as opposed to having those same operations handled by multiple machines. Typical multifunctional production machines equipped with contain five or more axes of motion and are capable of utilizing any combination of the three primary linear axes (X, Y, Z), three primary rotary axes (a, b, c), and/or additional axes parallel to the primary ones. This group of machines is commonly equipped with two or more tool systems and spindles and can operate in synchronous or asynchronous operating modes. Figure 1 shows major components of a MPM.

FIGURE 1
ANATOMY OF MULTIFUNCTIONAL PRODUCTION MACHINE



Adapted from https://www.mmsonline.com/articles/ merging-functions-for-better-efficiency

Figure 2 shows some of the part designs and production capabilities of MPMs. For instance, with 2-sided (front and back) features, MPM is capable to shape one end of a part in primary spindle while shaping the other end in secondary spindle.

FIGURE 2
PART DESIGNS AND PRODUCTION CAPABILITIES

Simultaneous shaping of two or more identical parts	Multi-spindle machine 
Simultaneous shaping of non-identical parts	
Shaping features on angular surfaces	
Simultaneous shaping of two sides (front and back machining)	

SELECTION CRITERIA

Advances in computer technology and applications in the manufacturing industry have transformed the CNC technology from stand-alone production units into complex integrated production centers. These systems can lead to significant savings in manufacturing operations owing to their ability to produce a variety of components in larger numbers and a multitude of features and geometries without the need for multiple setups and inter-machine part transfers. Figure 3 shows general selection factors as a decision-making guide for small shop entrepreneurs including part design features, material type, demand composition, production and business goals.

FIGURE 3
GENERAL SELECTION CRITERIA

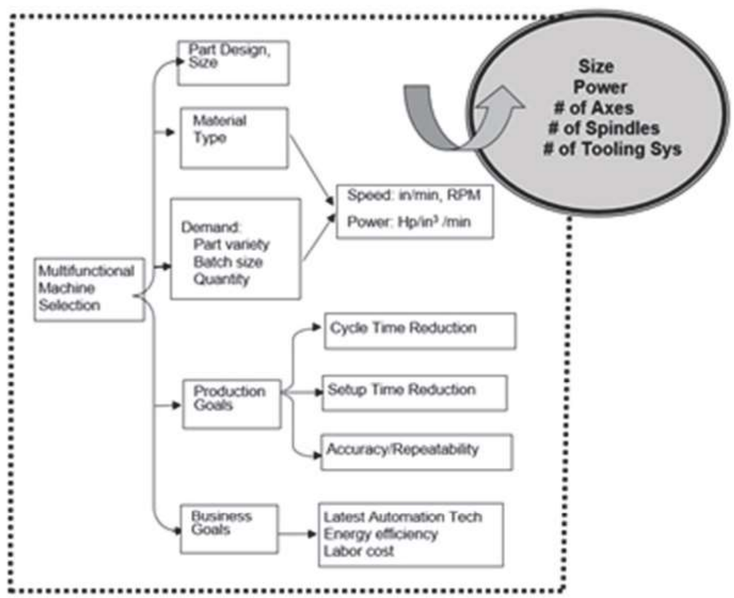
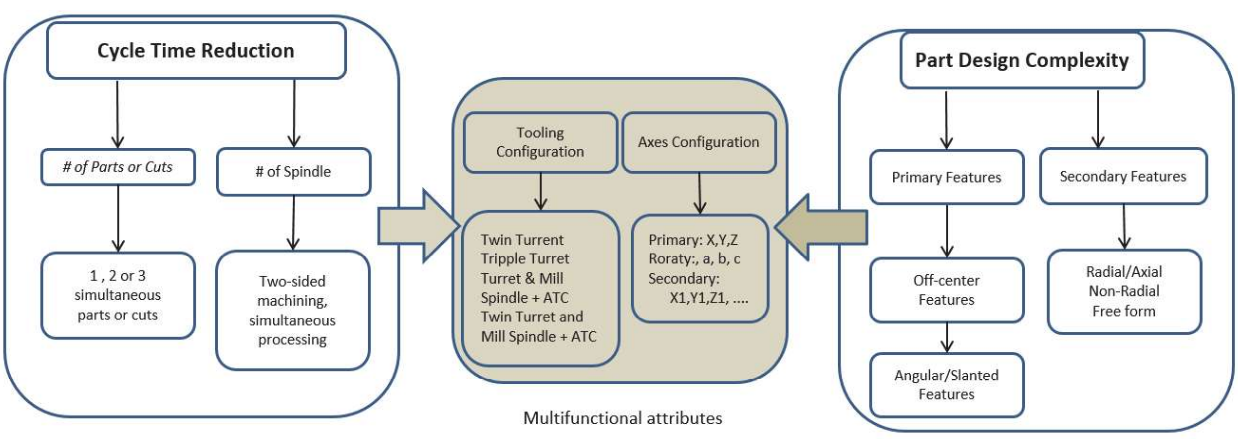


Figure 4 illustrates the relation between two primary decision-making criteria, cycle time reduction and part design complexity, as related to multifunctional features of MPM systems.

FIGURE 4
CYCLE TIME AND PART DESIGN IMPACT ON MULTIFUNCTIONAL FEATURES



PART DESIGN GUIDE

One of the major factors that influences the decision to select a MPM is the complexity of part geometry. Typically a multisided part or multisurface part requiring multiple setups is a good candidate for production on multifunctional machines. By machining complex shapes in a single setup, time is saved compared to performing the job in a series of setups. Five sides of a prismatic part, plus any combination of compound angles, complex sculptured parts, complex swept surfaces (e.g. turbine blades) can be shaped in one setup. Figures 5 and 6 exhibit examples of parts with various geometries with a guide to determine the type and number of axes of motions needed for a MPM. As an example, part design (f) has a slanted groove on a tapered surface. For shaping this type of geometry, a MPM machine with 5 axes of motions (X,Y,Z, b, c) would be needed.

FIGURE 5
PART DESIGN EXAMPLES AND REQUIRED AXES OF MOTION

Part Design (a)	Axis	
2-sided design	X	✓
	Y	✓
	Z	✓
	a	
	b	
	c	✓
	X1	
radial feature	Y1	
	Z1	

Part Design (b)	Axis	
flat radial features	X	✓
	Y	✓
	Z	✓
	a	
	b	
	c	✓
axial off-center features	X1	
	Y1	
	Z1	

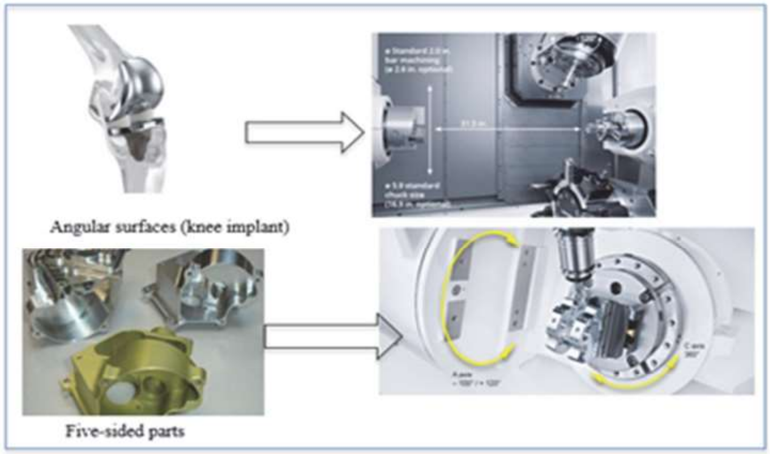
Part Design (c)	Axis	
	X	✓
	Y	✓
	Z	✓
	a	✓
	b	✓
	c	
angular swept surfaces	X1	
	Y1	
	Z1	

Part Design (d)	Axis	
	X	✓
	Y	✓
	Z	✓
	a	
	b	
	c	✓
radial features	X1	
	Y1	
	Z1	

Part Design (e)	Axis	
	X	✓
	Y	✓
	Z	✓
	a	✓
	b	
	c	✓
Five-sided features	X1	
	Y1	
	Z1	

Part Design (f)	Axis	
	X	✓
	Y	✓
	Z	✓
	a	
	b	✓
	c	✓
slanted features	X1	
	Y1	
	Z1	

PART DESIGN COMPLEXITY VS. MOTION AXES



Courtesy of DMG Mori Inc.

MATERIAL VS. MACHINE POWER

One of the basic requirements evaluated when determining power needs for material removal processes is the type of materials being processed. This will determine the levels of critical parameters such as spindle speed, torque, and high-speed horsepower. If material removal operations mostly involve shaping soft materials like aluminum or brass, the machines require higher speeds for finishing. On the other hand, if the operations mostly involve processing hard materials like steel or titanium the desired machines should encompass elements like low-speed torque, and rigidity. A related factor is production rate which depends on volume, order due date. This in turn impacts power needed to match material removal rate (hp/In3/min). Table 1 shows sample data for amount of power needed for milling various types of metals. Based on this data, the motor horsepower required for the milling operation can then be matched to the horsepower capability of the machines under consideration. For example, a true 40 HP machine can remove aluminum well over 200 cubic inches per minute.

TABLE 1
PROCESSING POWER NEEDS FOR SELECTED MATERIALS

Material	Unit Power hp/In3/min
	Milling
	Carbide Tools
Steels	1.4
Plain Carbon	1.9
Alloy Steels	2.2
Tool Steels	2.6
Cast Irons	0.8
Gray, Ductile	1.4
Stainless Steels	1.7
Titanium	1.4
Nickel Alloys	2.4
Aluminum Alloys	0.4
Magnesium Alloys	0.2
Copper Alloys	0.8

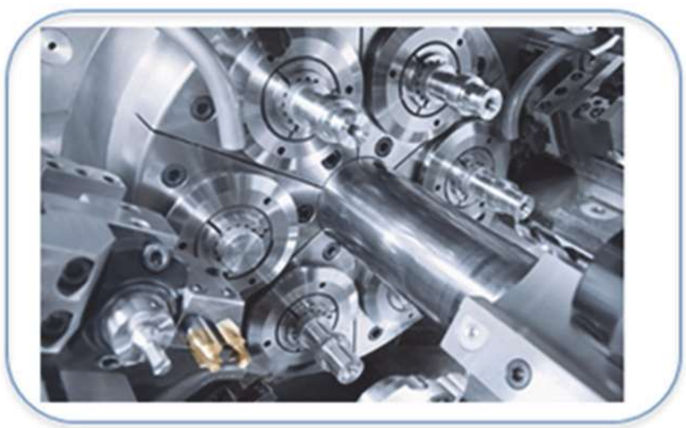
PRODUCTION GOALS

Before adopting a multifunctional production system, small business entrepreneurs must have a clear understanding of the production goals for using such complex technology and major capital investment. Primary questions to be investigated are: what is the expected performance of the new machine? Will there be high quality parts with less waste and shorter cycle times being made? Will the business strategy focus on flexibility in responding to product variety? Does the new equipment give the company an advantage over competitors?

Cycle Time Reduction

Most multifunctional machining systems are capable of processing multiple parts simultaneously using multiple spindles and/or axes of motion (Fig 7). Owing to these attributes, once material is loaded on the machine, a completely finished product is output allowing substantial reductions of in-process time.

FIGURE 6
MULTISPINDLE MACHINE



Courtesy of DMG Mori Inc.

Production Flexibility

A key feature in MPM system is the flexibility, which takes various forms from machines that can do more because of multi-axis, multi-tool, and multi-spindle capabilities to those that can adapt to changes in product and market demand. MPM systems make low-volume work practical because there is less fixturing, equipment, and labor involved. This is particularly beneficial in situations with small batch sizes, a high variety of parts and highly specialized components where part and tool changeover time might be substantial. Another measure of flexibility is the ability to use various stock geometries. With a multifunctional system, a small business is no longer locked into using certain stock geometries, i.e. square or rectangular stock because a part involves a lot of milling or round stock because the part requires turning operations.

Lean Manufacturing

Multifunctional can contribute to a leaner operation by reducing non-value added times such as setup time as well as process simplification and streamlining. One such opportunity is setup reduction. Parts requiring multiple setups might be appropriate candidates for production on MPM systems. In addition to a reduction in the number of setups, setup time to total processing time can be used as an appropriate measure if the majority of time is spent on setup rather than production.

Quality Control

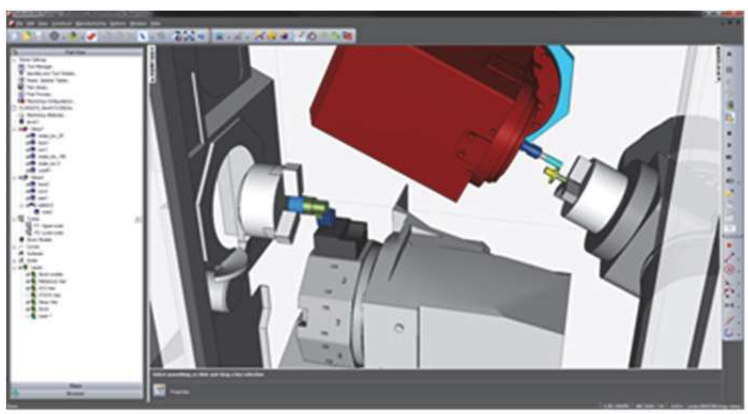
MPM systems have the potential to improve part accuracy by not having to re-positioning parts between operations, which eliminates the risk of stacked tolerances, reduces scrap rates and eliminates re-fixturing.

CAM SOFTWARE

With complex machinery comes inherent programming challenges (Waurzniak, 2013). The increasing sophistication of MPM systems require CAM (computer-aided machining) software capable of programming and simulating simultaneous operation of multiple axes, spindles and turrets. Several factors must be taken into consideration for selecting a CAM software:

- A realistic simulation of an exact replica of the machine tool (Fig. 8). This feature gives the user more accurate information to use and a 3D life-like environment exactly as the machine behaves on the shop floor.
- Built-in collision avoidance in multi-axis motions
- Ease of use and smart applications that can reduce user inputs. In other words, 3D model automatically defines the volume of material to be machined with fewer clicks.
- Technical support and training
- Initial cost and subsequent license update costs

FIGURE 7
MPM OPERATION SIMULATION



ECONOMICAL FACTORS

For small manufacturing businesses, the driving force for acquiring advanced multifunctional production machines is meeting higher production capacity needs and/or improving methods and technologies while gaining a economical return on investment. In determining ROI, acquisition, operation, maintenance and decommissioning costs should be examined. Acquisition costs include purchase price, installation and training costs. Operating cost involves direct labor cost, consumables (coolant, lubricant, etc.) and spare parts. Maintenance costs include preventive maintenance and repair costs. For decommissioning, resale value need to be considered. Table 2 shows pricing data and multifunctional features of several machines' make and model.

TABLE 2
COMPARISON OF SELECTED BRANDS/MODELS

Make	Model	Mill_Turn	# of Turrets	# of Spindles	Mill Spindle	# of X Axes	# of Y Axes	# of Z Axes	B Axis	Rotary B Axis	C Axis	Power, hp	Price
Eurotech	Kobra 20 SLY B	✓		2		2	1	2			2	3	$150,000
Mazak	Integrex e-500HS	✓		2	✓		1					40	$499,000
	Cybertech4500MT		2	2			0					50	
DMG Mori	NTX2000	✓	1	2	✓		1		✓	✓	✓	30	$400,000
	NZX 2000	✓	3	2			3		✓		✓	33	$400,000
	DMU 50	✓		1			1		✓		✓	50	$290,000
Nakamura	Super NTM3	✓	3	2			2		✓		✓	35	
	Super NTX	✓	2	2	✓		1		✓	✓	✓		
	WY-100	✓	2	2		2	2	2			2	15	$370,000
	Super NTMX	✓	1	2	✓		1		✓	✓	✓		$300,000
Index	C100	✓	3	2			2				✓		
Ganesh	CYCLONE 70TTMY	✓	2	2		2	2	2	✓		2	20	$190,000

As can be seen from this sample data, the prices range between $150,000 to $499,000 depending on the offered features and power. These features must be considered for justification of such investment along with ROI or payback calculation. It is possible to have a high ROI and a low profitability, and the opposite is true. Entrepreneurs should look at a new technology upgrade from both standpoints. In performing an ROI analysis, they should also consider the long-term impact of the investment. All in all, while profitability may initially be higher when looking at a lower priced machine, due to the long term benefits such as reliability, durability, flexibility, reduced cycle time, and better part quality, the higher quality machine purchase can be a most beneficial choice.

CONCLUSION

New technology can help small manufacturing shops and entrepreneurs to lower their cost of entry and increase their speed to market. Multifunctional production machines provide enormous capability for manufacturing a wide range of parts. In this study, we presented a basic guideline for configuring a machine that meets product design, material type and production goals. While these systems are capable of meeting several production goals such as cycle time reduction, minimizing non-value added times and concurrent processing of multiple parts, in most cases they require high capital investment. An ROI or payback analysis should take into account several factors discussed in this study as well as long-term benefits of higher quality machines. With right technology, forward-thinking entrepreneurs can lay the groundwork for long-term growth.

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