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A knowledge-based system for end mill selection

Prasad, K.[a], **Chakraborty, S.**[a,*]

[a]Department of Production Engineering, Jadavpur University, Kolkata, India

A B S T R A C T

In the present global competitive environment, manufacturing organizations are being forced to constantly develop newer methods/technologies for producing high quality products/components at the minimum possible cost to satisfy the diverse and dynamic needs of customers. Selection of a proper cutting tool within a process planning system is vital for the productive efficiency and cost effectiveness of a manufacturing process. In this paper, a knowledge-based system is developed in Visual BASIC 6.0 and subsequently implemented for selection of an appropriate end mill for a given machining application from a set of feasible alternatives. Although, there are some published research papers on the applications of knowledge-based systems for selecting of cutting tools, none of them has investigated its scope for choosing a suitable end mill from a comprehensive list of options available on the market. The developed system first narrows down the list of end mills based on some predefined parameters as set by the process planner and then ranks the feasible end mills according to their suitability for the desired machining application. While ranking the end mill alternatives, criteria weights are determined using Shannon's entropy method to avoid subjectivity in judgments. It also guides the process planner in identifying the corresponding speed and feed for different combinations of workpiece material and machining operation.

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**Corresponding author:*
s_chakraborty00@yahoo.co.in
(Chakraborty, S.)

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1. Introduction

The business dynamics of manufacturing sector is changing at a lightening pace with advancement in technologies and innovation in product development. Therefore, manufacturing organizations in order to stay relevant in this highly competitive global market have to look ways to achieve manufacturing excellence through producing new cutting-edge products/components more economically. A product/component can be manufactured using a diverse range of processes, like material removal, casting, forging etc. It is observed that material removal through machining operation is the most extensively used manufacturing technique among all the processes because invariably every product undergoes through this operation at one point or the other while utilizing different types of cutting tools [1]. Material removal is an expensive process as it involves removal of substantial amount of material from the workpiece in the form of chips with a view to generate the desired product shape. The expensive nature of material removal can also be attributed due to the considerable amount of energy spent in this process. Besides, effective monitoring of cutting tools facilitates superior efficiency of the machine tools [2, 3]. Therefore, appropriate cutting tool selection and its correct application are the key elements to profitable machining, which are completely in line with the overall objective of achieving manufacturing excellence in an organization.

There are several different kinds of cutting tools available in the market today, each serving diverse purposes and applications. These cutting tools can be broadly classified into two groups, i.e. single point and multi-point cutting tools. End mill is one of the most widely employed multi-point cutting tools, which is indispensible in many industries, like aerospace, ship building and automobile for machining varying complex-shaped components [4]. It is typically mounted vertically on a machine tool and has two or more helical flutes/cutting edges. The main advantage of an end mill is that unlike any other type of milling cutter, it is configured to cut with both its tips and sides. End mill can operate effectively and efficiently only when it is capable to withstand the heat generated during the cutting process. In addition, the material from which the end mill is manufactured must be harder as compared to the material being cut. End mill should have a specific geometry according to the requirements of a considered machining application in order to provide correct clearance angles so that only the cutting edge of the tool makes contact with the workpiece material. It is also crucial to ensure that the end mill is able to machine the complete work surface without any interference [5]. Therefore, the type of end mill and its related geometry depend on the material being cut and complexity of the machining operation being performed.

These are some important factors that the process planners need to consider while selecting an end mill in order to ensure its optimal productive working life. Moreover, there is a wide range of end mill varieties available in the market with respect to design styles and material choices. As the number of influencing criteria and available alternatives increases, it becomes quite hard and almost impossible for a human brain to examine the relation between those criteria and alternatives while making a valid conclusive decision. Additionally, a suitable end mill can drastically minimize the final roughness of a milled surface [6]. Thus, selection of an appropriate end mill for a specific machining application requires a thorough knowledge regarding its applicability, capability and economy, and related effects of the considered evaluation criteria on the machining operation. Besides selection of an inappropriate end mill may lead to infeasible and inconsistent process plans. Incorrect process plans often need to be rejected in the shop floor and the new ones generated on an impromptu basis result in overall cost escalation. So, an adherent need for development of a knowledge-based system which can select an appropriate end mill from a wide range of alternatives available from different manufacturers cannot be ignored. Therefore, this paper proposes development and subsequent deployment of a knowledge-based system for solving end mill selection problems for varying machining applications.

2. Literature review

Arezoo et al. [7] designed a knowledge-based system for identification of cutting tools and conditions for turning operations. Carpenter and Maropoulos [8] proposed a methodology to choose tools for a wide range of milling operations based on a comprehensive set of user-defined selection and optimization criteria. Sorby and Tonnessen [9] presented a methodology for optimization of cutting data of high speed flank milling in order to find out its optimal cutting parameters. Čuš and Balič [10] developed an algorithm to identify the optimal tool version and cutting conditions from different tool manufacturers' commercial databases. For a concurrent engineering environment, Edalew et al. [11] developed a computer-based intelligent system for automatic selection of cutting processes and tools. Wang et al. [12] proposed a new methodology employing genetic algorithms for selection of the optimal cutting conditions and cutting tools in multi-pass turning operations based on a complete set of optimization criteria. Zhao et al. [13] combined a commercial computer-aided design system and an expert system for selection of cutting conditions and tools for turning operation. Byrne et al. [14] reviewed some of the main developments in the domain of cutting technology over the last 50 years in order to provide a roadmap for its future development. Muršec and Čuš [15] developed an integral model for selection of the optimal cutting conditions on the basis of various databases offered by the tool manufactures while taking into account some limitations of the cutting processes. Oral and Cakir [16] determined the computer-aided optimal operation and tool sequences for use in generative process planning system of rotational parts. Svinjarević et al. [17] discussed about the benefits of implementation of a cutting tool management system in an organization specializing in metal cutting processes. Wang et al. [18] developed a performance-based machining optimization system for predicting the optimal cutting conditions in turning operations. Arshad et al. [19] presented a cutting tool management system to help the end user in selecting the best cutting tool and parameters for cutting operation. Ostojic et al. [20] designed a computer-aided system for efficient selection of cutting tools for machining processes, including turning, drilling, milling and grinding operations. Vukelic et al. [21] presented an integrated software solution for cutting tool selection based on modular principle. Chougule et al. [22] developed an expert system capable of selecting appropriate carbide cutting tools for various turning operations.

It is thus observed from the past literature review that an extensive work on cutting tool selection and optimization of various cutting parameters for different machining operations has already been carried out. But, it is noteworthy to mention here that those research works are mainly intended to identify the most suitable cutting tools with respect to a set of pre-determined performance criteria, while ignoring the interrelationship between various technical, strategic and economic attributes. Moreover, the published research papers in the area of milling cutter selection are really scarce in number. None of the past researches has proposed a logical and systematic procedure for solving end mill selection problems. Selection of the most appropriate and also theoretically correct end mill is a complex task due to the presence of several evaluation criteria which are often conflicting in nature. Therefore, in this paper, a knowledge-based system is designed and developed in Visual BASIC 6.0 for solving end mill selection problems. It is supported by an exhaustive database for end mills containing information on their various technical specifications and controlled by a set of rules for specific machining applications. Its applicability and potentiality is demonstrated by three real-time industrial examples.

3. Knowledge-based system for end mill selection

Quick and easy access to the pertinent information for decision-making on end mill selection for a given machining application is of vital importance to attain competitive edge and manufacturing excellence. This paper presents a knowledge-based system for selecting end mills in accordance with the specific machining application requirements of the present day manufacturing industries. The developed system generates a set of feasible end mill alternatives for the given application from a comprehensive list of options available in the market, and subsequently provides their ranking preorder. It is often observed that the change in machining conditions and generated shape features of the final component considerably affect the efficiency and productivity of an end mill. Hence, the process planner needs to have a clear understanding about the selection problem. The process planner first provides the required information with respect to tool material, type of use, workpiece material etc. Different evaluation criteria, like number of flutes, cutting diameter, cutting length etc. are then shortlisted. Next, the required ranges of values for those recognized evaluation criteria are specified. This knowledge-based system is designed to first discard those end mills which do not satisfy the identified machining application requirements and gradually narrow down the list of feasible solutions at each step of the selection procedure. Finally, the set of feasible end mill alternatives is ranked with the identification of the most suitable choice. The framework of the developed knowledge-based system for end mill selection is exhibited in Fig. 1.

End mills available in the market can be broadly classified into various categories. Each category may further be divided on the basis of its specific application and special geometry. The initial step in the development process of this knowledge-based system comprises of creation of the related database for various types of end mills available in the market. The pertinent information for the end mills is accumulated from the brochures and catalogues of different manufacturers available online. Then, this collected information is stored into MS-Access option of Visual BASIC 6.0 and an exhaustive database containing technical specifications of a wide variety of end mills is thus documented. With the introduction of new end mills and inclusion of more added features, like geometry of the tool and other related specifications, it can be updated from time to time with the active participation of the knowledge-based system builder.

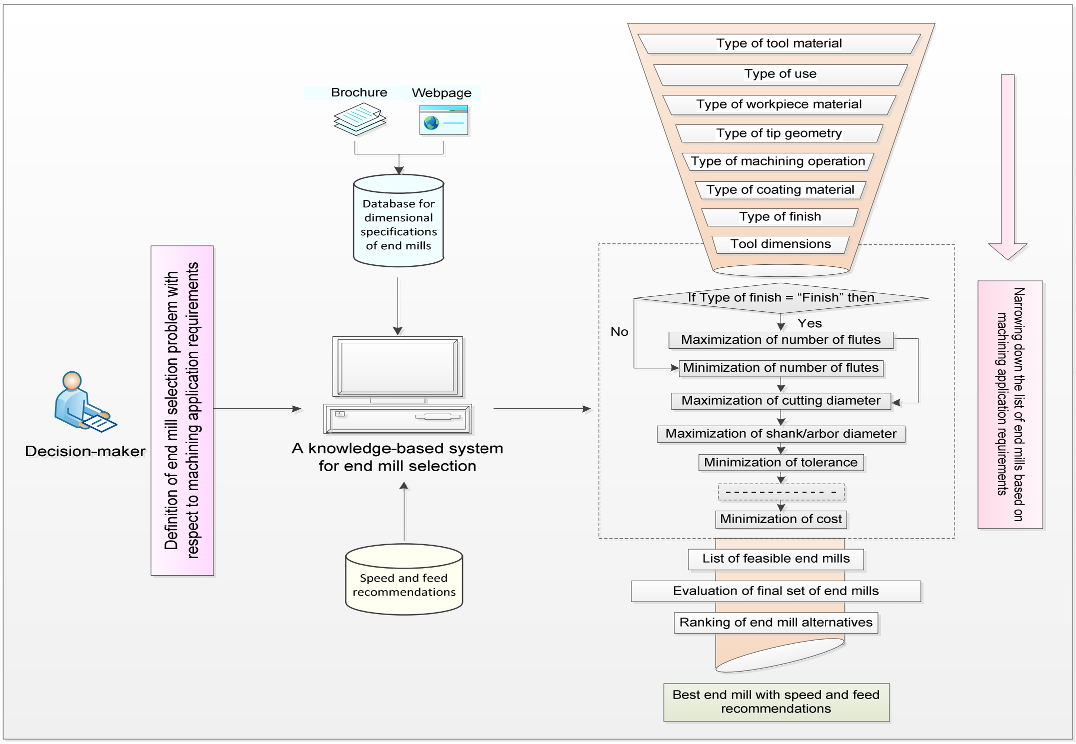


Fig. 1 Framework for knowledge-based system for end mill selection

Once the database is created, the next step is to generate a set of feasible alternative end mills based on various criteria as specified by the process planner according to requirements of a particular machining application. End mill removes material from the workpiece simply by means of shear deformation. So, the material of end mill needs to be harder than that of the workpiece, which is to be machined, and it must also be able to withstand the heat generated during the material removal process. A wide range of materials is being utilized to manufacture end mills. Therefore, tool material is an important consideration while selecting an end mill. Some of the common tool materials used for manufacturing of end mills are listed as below:

a) *Carbide:* It has comparatively higher values for hardness, thermal conductivity and Young's modulus, which facilitate its usability as an efficient tool material. Tools made of carbide can operate at much faster speed because of its extreme hardness. This allows the milling cutters to withstand high cutting temperature and provides excellent wear resistance. Carbide also offers better rigidity than high speed steel (HSS), which enables the end mill to perform the machining operation with higher degree of dimensional accuracy and superior surface finish.

b) *HSS:* It accounts for the largest tonnage of tool materials currently being utilized. It provides good wear resistance and is less expensive than cobalt or carbide end mills. It is used for general purpose milling of both ferrous and non-ferrous materials. HSS tools are tough and suitable for interrupted cutting, and are employed to manufacture tools of complex shapes, such as drills, reamers, taps, dies and gear cutters.

c) *HSSCoM42:* It comprises of molybdenum-series HSS alloy with additional 8 % cobalt content. It provides better wear resistance, and higher hardness and toughness than HSS. There is very less chipping or micro-chipping under severe cutting conditions allowing the tool to run 10 % faster than HSS. This results in achieving excellent material removal rate (MRR) with better surface finish.

d) *HSSCoPM:* Powdered metal (PM) exploits the benefits of both, i.e. toughness of cobalt HSS, and heat and wear resistance properties of micro-grain carbide tools. It is used in those applications, which require higher MRR and are vulnerable to vibrations, like roughing operation. It is a cost effective alternative to solid carbide.

e) *Ceramic:* Many grades of ceramic are utilized for manufacturing of end mills. Ceramic grades are characterized by good wear and abrasive resistance, non-conductivity and superior thermal properties. Ceramic is recommended for machining cast irons and nickel-based superalloys at intermediate cutting speeds.

f) *Diamond:* Industrial diamond grades, such as polycrystalline diamonds (PCD) are normally made by sintering many micro-size single diamond crystals at high temperature and pressure. They have good fracture toughness and thermal stability. They are often used for special applications, like very high-speed machining of aluminium-silicon alloys, composites and other non-metallic materials.

End mills can also be grouped into three categories based on their usage, which are as follows:

a) *General purpose:* It also symbolizes multi-purpose end mills, which can be employed for a wide range of applications and workpiece materials. They favour high productivity while keeping the number of tool changes as minimum as possible. General purpose end mills are quite economical, and at the same time, have high manufacturing flexibility.

b) *Special purpose:* They are employed for specific machining operations, such as thread cutting, die-sinking, corner rounding etc.

c) *High performance:* As the name indicates, they are applied in highly specialized fields for manufacturing components of aircraft, marine structures, turbines etc. where high precision and close tolerances are required.

Manufacturing organizations produce an extremely large variety of products/components which are machined from different workpiece materials. Each workpiece material has a unique set of characteristics that are influenced by its alloying elements, heat treatment process, hardness etc. These factors combine to strongly influence the choice regarding the cutting tool geometry and grade. Therefore, the workpiece materials as considered for this knowledge-based system are divided into the following seven major groups:

a) *Steel:* It refers to a broad category of alloys containing primarily iron with little amount of carbon and other alloying elements. The machinability of steel is normally good, but can differ depending on material hardness, carbon content etc.

b) *Stainless steel:* It is a steel alloy with a minimum of 12 % chromium content by mass and has non-magnetic properties. Stainless steel exhibits superior resistance to corrosion and is available in different grades.

c) *Cast iron:* It is a group of iron-carbon alloy with a carbon content greater than 2 %. Grey cast iron, malleable cast iron and ductile cast iron are quite easy to machine, whereas, white cast iron, compacted cast iron and austempered cast iron are comparatively difficult to machine.

d) *Non-ferrous material:* Softer metals, like aluminum, copper, brass etc. belong to this category. Machinability property of these materials usually fluctuates with their varying alloying elements.

e) *Special alloy:* It comprises of a large number of iron, nickel, cobalt and titanium-based alloy materials. Special alloy is very similar to stainless steel but is much more difficult to cut, which reduces the tool life of end mills.

f) *Hardened steel:* This group includes steels with hardness between 45-65 HRc (Rockwell hardness). Hardened steel is difficult to machine and it generates excessive heat during cutting operation.

g) *Titanium/exotic metal:* This refers to a category of different precious and exotic metals, such as titanium, tungsten, platinum etc.

A number of tip geometry options for end mills are also available for generating the desired shape feature on a given workpiece material. Various kinds of tip geometry options for the end mills are enlisted as below:

a) *Square:* Cutting tips are square or straight-ended with no radius, chamfer or other finish feature.

b) *Ball:* Cutter ends with a hemispherical ball whose radius is one half of the cutter diameter. It is useful for machining semicircular groove or radii on a workpiece.

c) *Radius:* Cutting tool comprises of radius on tips of straight flutes.

d) *Chamfer:* Cutter sides or ends contain an angled section on tip to produce an angled cut or a chamfered edge on the workpiece.

The type of finish is also an important consideration while selecting end mills. There are broadly two finish preferences that can be opted while employing end mills:

a) *Roughing:* Tool material, flutes and/or cutter geometry are designed for rapid and heavy material removal. Roughing cutters are typically utilized to machine workpieces for initial cutting stages, i.e. where cutting somewhat more than the desired dimension is not a problem.

b) *Finishing:* A minimal amount of material leftover after the roughing operation is removed with a finish cut.

Coatings are applied on the end mills to enhance their wear resistance property and isolate the area where heat is generated from the substrate of the tool. If coatings are not applied, heat produced during the machining operation can potentially accumulate to negatively affect the tool life. Most of these coatings are usually referred to by their chemical compositions, such as:

a) *Aluminium Titanium Nitride (AlTiN):* It is ideal for high temperature cutting operation of a diverse range of materials, such as titanium and nickel alloys, steel, stainless steel and cast iron. AlTiN is an extremely tough coating material capable of withstanding extreme machining conditions developed during heavy and interrupted cutting operations.

b) *Aluminium Titanium Nitride + Silicon Nitride (nACo):* This coating material is very well suited for high performance milling applications. It has a great ability to resist at high temperature up to 1200 °C before getting oxidized and worn out.

c) *Physical vapor deposition (PVD) diamond:* Thin diamond films are applied to cutters to increase their service life and abrasive resistance. This coating is a standard choice among the die and mold shops for machining graphite.

d) *Titanium Carbonitride (TiCN):* It has an exceptional high hardness and low coefficient of friction, which provide excellent wear resistance. TiCN's high lubricity facilitates easy chip flow, prevents formation of build-up edges, and reduces cutting forces and temperature.

e) *Zirconium Nitride (ZrN):* ZrN is typically used to coat end mills that are employed for machining non-ferrous materials, such as aluminum, brass, nickel alloys, plastics etc. It also provides good abrasive resistance and lubricity properties.

An assortment of machining operations can be performed using end mills, which comprise of a) side milling, b) slotting, c) profiling, d) radius cutting, e) slotting with radius, f) pocketing, g) chamfering, h) drilling, i) thread cutting, and j) corner rounding.

The developed system narrows down the list of feasible end mill alternatives based on the above-considered parameters with respect to the specified machining application requirements. Then, the selection procedure moves to the next stage where various evaluation criteria with respect to the dimensional specifications of the end mills are shortlisted, and subsequently, ranges of values for those identified criteria are provided. The following 12 important dimensional specifications are considered in this system, which affect the final end mill selection decision.

a) *Number of flutes:* It signifies the number of cutting edges in the end mill.

b) *Cutting diameter* (inch)*:* It is the diameter of the full-tool which cuts the workpiece material.

c) *Shank/arbor diameter* (inch)*:* It refers to the diameter of mounting shank or arbor.

d) *Flute/cutting length* (inch)*:* It is the total length of a cutting edge.

e) *Overall length* (inch)*:* It denotes the total tool length, including integral shank, if present.

f) *Tolerance* (inch)*:* It represents the dimensional closeness to a given specification.

g) *Width of cut* (inch)*:* It is the depth of cut in radial direction.

h) *Cost* (USD)*:* It symbolizes the procurement cost of a single end mill.

i) *Radius/corner size* (inch)*:* It either signifies the dimension of radius of the end mill with radius type tip geometry, or represents the angle of cutter of the end mill having tip geometry as chamfer.

j) *Taper* (°)*:* It measures the gradual reduction in the diameter of a cylinder towards one of its end.

k) *Drill point* (°)*:* It is the angle formed at the tip of the end mill utilized for drilling holes.

l) *Pitch* (inch)*:* It is the distance from the crest of one thread to that of the next thread.

These 12 above-mentioned dimensional specifications may be either beneficial or non-beneficial in nature depending on the machining applications which ultimately affect the shape feature generated on the end product. For example, the number of flutes can range from two to eight. Fewer number of flutes offer efficient chip removal and high MRR, whereas, more number of flutes provide a smoother finish. Beneficial attributes are always required in higher values, whereas, non-beneficial attributes are preferred with smaller values.

Once the list of feasible alternatives is elicited after the ranges of values are entered, it is again required to be critically analyzed and ranked with a view to recognize the most suitable end mill. Evaluation and ranking of the feasible end mills with respect to the given dimensional specifications needs formation of the related decision matrix. This decision matrix is developed while extracting the pertinent information for the feasible end mills from the database integrated with the knowledge-based system.

Shannon's entropy method [23] has a significant role in decision making under uncertain environment. It is a well-accepted technique to estimate criteria weights, particularly in those situations, where obtaining a suitable weight (importance) based on the preferences and decision making experiments are impracticable. In other words, it is capable of measuring uncertainty in the information formulated using probability theory. Moreover, it facilitates comparisons of different criteria through converting different scales and units into common measurable elements. In this paper, the priority weight for each evaluation criterion is calculated using this method to eliminate subjectivity in judgments. The performance scores of the feasible end mills are finally calculated employing the following equation:

$$PS_i = \sum_{j=1}^{n} w_j \times (\text{Normalized value})_{ij} \; (i = 1, 2, \ldots, m; j = 1, 2, \ldots, n) \tag{1}$$

where w_j is the weight for j^{th} criterion, m is the number of feasible end mills, and n is the number of the considered criteria. The normalized value showing the normalized performance of i^{th} end mill with respect to j^{th} criterion is derived from the decision matrix of a given end mill selection problem using linear normalization technique. The ranking of the feasible end mills is then derived based on their descending performance scores, and subsequently, the most appropriate end mill for the given machining application is identified along with its ideal parametric settings.

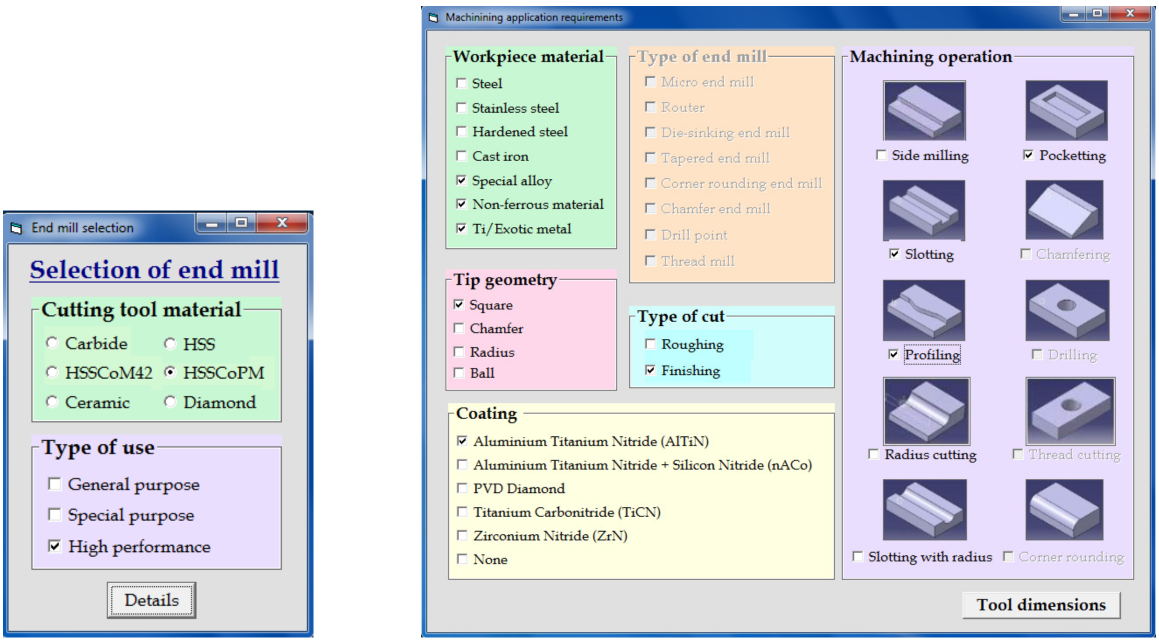
4. Illustrative examples

The following three end mill selection problems are formulated and subsequently solved to demonstrate the applicability and robustness of the developed knowledge-based system.

4.1 End mill for aerospace applications

In this selection problem, the most suitable end mill for aerospace applications that can perform finishing operations needs to be identified from a wide range of available alternatives. The components used in aerospace industries are generally thin-walled and complex shaped. They need to be machined within close tolerances. Additionally, machining of aerospace components is generally carried out at higher speed with increased MRR and relatively low cutting forces. Further, it is observed that materials utilized for aerospace components should have higher strength, hardness, elasticity, toughness, ductility and malleability, but lower brittleness.

The selection procedure starts with identification of the proper cutting tool material that satisfies the machining requirements of aerospace components. It is observed after careful review that end mills made of HSSCoPM enable in achieving comparatively higher MRR with less power requirement while providing excellent cutting strength and wear resistance. So, ‘HSSCoPM’ is opted as the cutting tool material in Fig. 2(a). Next, the process planner needs to provide the type of use, which in this case, is ‘High performance’ as it is in sync with the complex machining requirements of aerospace components. Special alloy, non-ferrous material and Ti/exotic metal are selected as workpiece materials in the subsequent step because they satisfy the physical requirements of materials employed in aerospace industry. The tip geometry for this application is chosen as ‘Square’ due to its ability to remove material while maintaining excellent finish. ‘Finishing’ is opted as the type of cut according to the end mill requirement. Coating provides additional protection against corrosion and abrasion, increases hardness, and improves overall life of the end mill. In this case, coating of AlTiN is more effective than any other available option as it facilitates exceptional oxidation resistance and works well in high demanding machining applications. Complex shape geometries often need to be generated on aerospace components, and therefore, ‘Pocketing’, ‘Slotting’ and ‘Profiling’ are chosen as the required machining operations among various options available in the knowledge-based system. ‘Tool dimensions’ functional key, as exhibited in Fig. 2(b), is now pressed to derive a narrowed down list of end mill alternatives satisfying all the above-mentioned requirements.



(a) (b)

Fig. 2 Requirements of an end mill for aerospace applications

In the next stage of this selection procedure, the narrowed down list of end mill alternatives is further evaluated based on some important evaluation criteria, which are identified here as shank/arbor diameter, flute/cutting length, overall length, tolerance and width of cut. All these chosen evaluation criteria are beneficial in nature, except tolerance. The desired ranges of values for these five criteria are then entered into the corresponding empty cells, which can be generated on pressing 'Input range' key. Some of the already feasible alternative end mils are discarded at this stage based on their incapability to meet the specified tool dimensional requirements. Finally, a set of 15 end mill alternatives satisfying all the preset machining application requirements is obtained after pressing 'Feasible alternatives' functional key. At this stage, the knowledge-based system provides two options, i.e. either to select all the end mill alternatives by pressing 'Select all' functional key or to choose the end mills individually from the already generated final list. Here, all the end mill alternatives are selected for final evaluation. On pressing of 'Compare' functional key, the corresponding decision matrix is automatically generated from the database, as shown in Fig. 3. The priority weights for the five evaluation criteria and the performance score for each end mill are subsequently calculated at the backend of the developed system to rank all the candidate alternatives.

Here, ERFPM-1616 emerges out as the most suitable end mill for the given aerospace applications. Its technical details along with a real-time figure can be obtained after pressing 'Tool description' key in Fig. 4. The developed system also guides the process planner in deciding the values of surface feet per minute (SFM) and chip load per tooth (CLP), which in turn represents the optimal speed and feed respectively for the finally selected end mill. Although the details regarding SFM and CLP are only the suggested starting points, they can be modified depending on the machine condition, depth of cut, type of coolant etc.

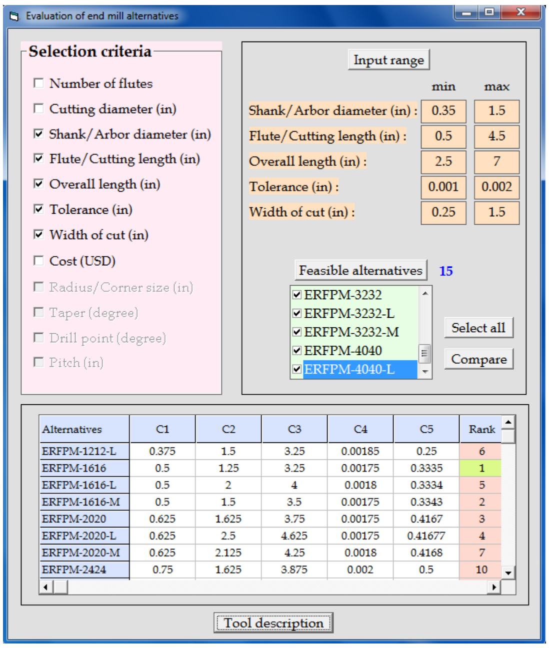


Fig. 3 Decision matrix for selection of end mill for aerospace applications

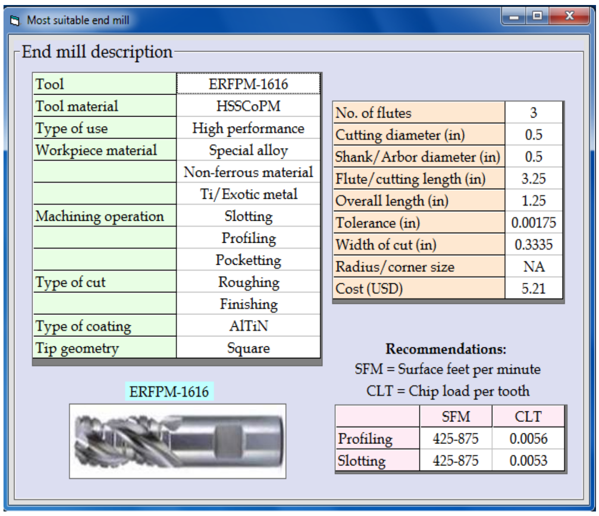


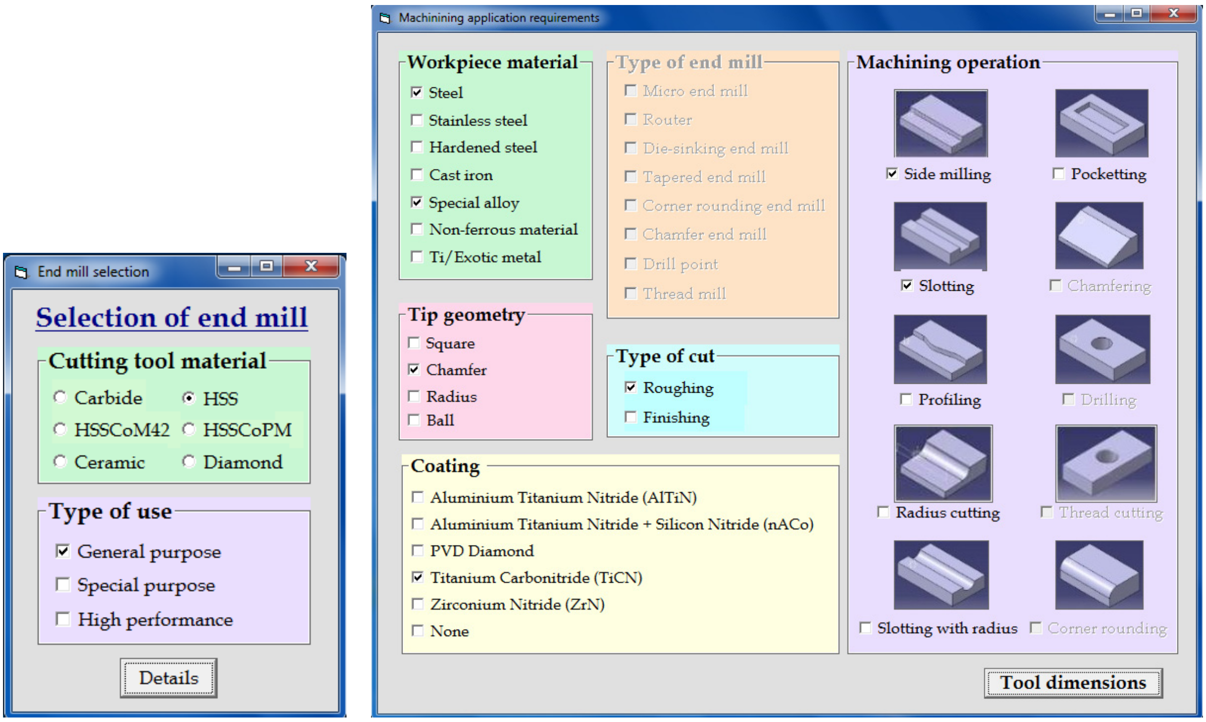
Fig. 4 Most suitable end mill for aerospace applications

4.2 End mill for general purpose milling operation

The aim of this selection problem is to choose the most appropriate end mill that can perform a wide variety of machining operations required in a small-lot-production process. The selected end mills should be versatile and flexible enough to meet the varying demands of small-lot-production. Moreover, these types of machining operations need end mills to be rigid and powerful in order to sustain cutting forces during the material removal process.

The initial step in identifying the best end mill for this selection problem is to choose the cutting tool material as ‘HSS’. The advantages of HSS over the other cutting tool materials are its strength to withstand comparatively high cutting forces and relatively low cost. HSS also performs well at intermittent cutting applications from the tool life point of view, which is an important consideration while selecting an end mill. Depending on the type of usage for the end mill, ‘General purpose’ option is chosen from the opening window of the developed system, as shown in Fig. 5(a). Next, ‘Steel’ and ‘Special alloy’ are identified as the workpiece materials owing to their widespread applications in manufacturing industry. The selected end mill should be able to operate for prolonged duration, and hence, tip geometry for the end mill is chosen as ‘Chamfer’ which offers longer tool life. TiCN film is an excellent all-purpose coating material that induces good repeatability and increases hardness of the end mill considerably. Thus, ‘Titanium Carbonitride (TiCN)’ is accepted as the coating option for this selection problem. Additionally, the end mills required for general purpose milling operation usually undergo heavy duty machining without any close dimensional tolerance for the end product. Therefore, ‘Roughing’ is opted as the type of cut to be performed. The machining operations in manufacturing industry usually comprise of production of flat vertical surface on the sides, and generation of key ways, grooves and slots of varying shapes and sizes on the workpieces. So, ‘Side milling’ and ‘Slotting’ are chosen as the machining operations to be performed, as exhibited in Fig. 5(b). In order to discard the unsuitable end mill alternatives and move into the next stage of the selection procedure, ‘Tool dimensions’ functional key is now pressed.

In this stage, five evaluation criteria, i.e. number of flutes, cutting diameter, flute/cutting length, overall length and cost are shortlisted based on which the feasible end mills are further examined for their suitability to perform the intended machining operation. Here, cost and number of flutes are non-beneficial criteria, which are always preferred with lower values. The range of values for each evaluation criterion is then entered into the corresponding empty cells, as exhibited in Fig. 6. A list of nine feasible end mill alternatives which satisfy the specified criteria values appears on pressing of ‘Feasible alternatives’ functional key. Here, all the nine end mill alternatives are evaluated. The most suitable end mill and the corresponding ranking preorder are obtained while pressing ‘Compare’ functional key.



(a) (b)

Fig. 5 End mill selection for general purpose milling operation

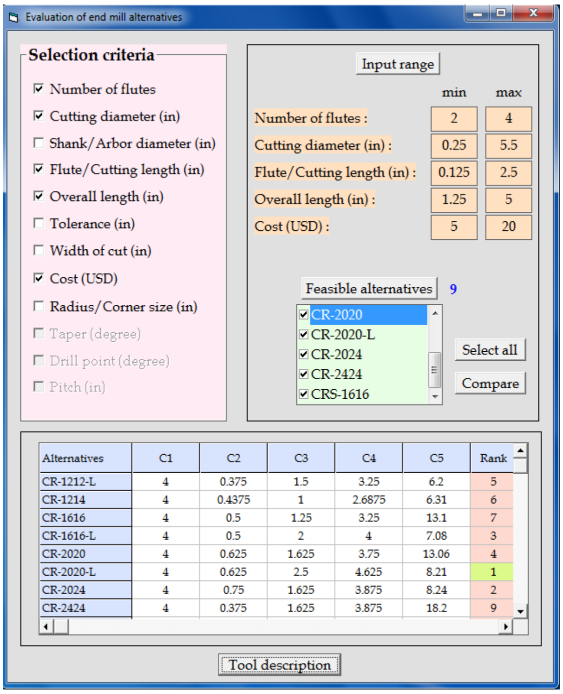


Fig. 6 Decision matrix for selection of end mill for general purpose milling

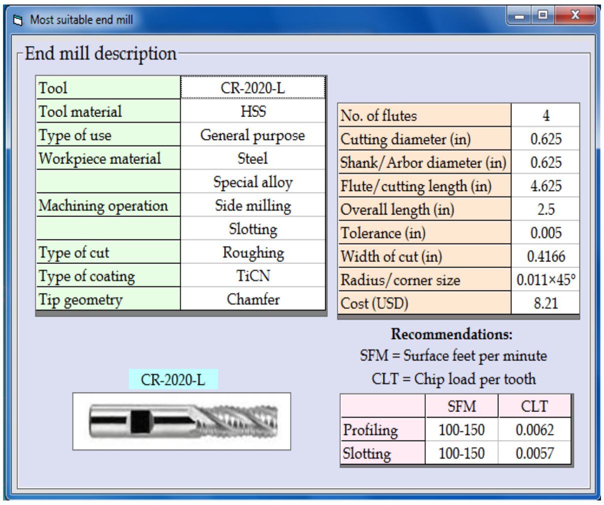
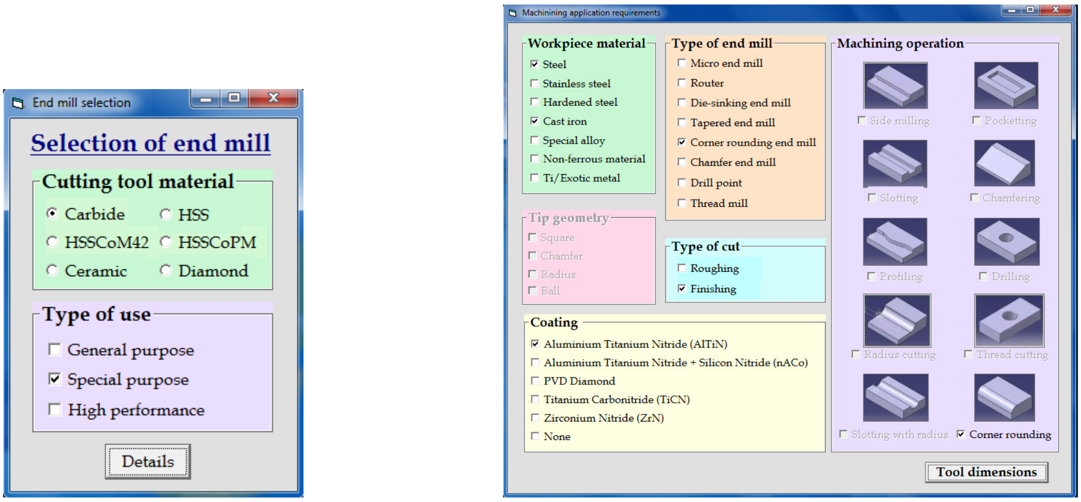


Fig. 7 Selected end mill for general purpose milling operation

It is noticed that CR2020-L is the most suited end mill for performing general purpose milling operations on workpiece materials, like steel and special alloy. The complete details of CR2020-L along with its real-time photograph, and suggestions regarding the corresponding SFM and CLP values are displayed in Fig. 7.

4.3 End mill for corner rounding operation

This example illustrates selection of an end mill which is designed for quick and effective rounding off operation of corners of finished components made of steel and cast iron. The first step in solving this problem is to select the proper cutting tool material. The tools made of carbide are more resistant to abrasive wear, thus protecting them from edge wear caused due to high abrasiveness of cast iron. They also resist cratering and heat deformation that may be caused by long chips of steel at higher cutting speeds. So, 'Carbide' is selected as cutting tool material, as shown in Fig. 8(a), entrusting on the above-mentioned characteristics of carbide tools. Corner rounding is a special category of machining operation performed for high volume production. Therefore, in accordance with the machining application requirements of the said selection problem, 'Special purpose' is chosen as the type of use. Consequently, 'Type of end mill' module is automatically enabled in the developed system with the selection of 'Special purpose' as type of use. Here, 'Corner rounding end mill' is identified as the type of end mill, as exhibited in Fig. 8(b). In this selection process, owing to the fact that the considered end mill variant does not possess specific type of end geometry, 'Tip geometry' option is disabled. Rounding of corner is considered as a finishing operation. Therefore, 'Finish' option is opted as the type of cut to be performed. Coating of AlTiN helps in protecting carbide tools from the detrimental effects of heat. It is acknowledged to be ideal for high speed and hard milling, especially in dry cutting operation. Keeping these properties in mind, AlTiN is chosen as the coating material for carbide tool. Corner rounding is the machining operation to be performed. Therefore, all the other machining operations are disabled except 'Corner rounding', as shown in Fig. 8(b). The end mill alternatives suitable for this machining application are then shortlisted after pressing 'Tool dimensions' key.



(a) (b)

Fig. 8 End mill selection for corner rounding operation

In this phase of the selection procedure, the extracted end mill alternatives from the first stage are further evaluated with respect to five more criteria, i.e. number of flutes, minor diameter, shank/arbor diameter, radius/corner size and cost. The range of values for each criterion is entered into the respective cells generated on pressing 'Input range' functional key. Once, all the necessary values are entered, this knowledge-based system elicits a list of 23 candidate end mill alternatives capable of performing the task of corner rounding operation on steel and cast iron after pressing of 'Feasible alternatives' functional key. Here, a list of 12 end mill alternatives is selected for final evaluation. Pressing of 'Compare' functional key develops the corresponding decision matrix and calculates the performance score for each alternative to identify the best end mill choice. The ranks of the considered end mill alternatives are displayed in Fig. 9.

Fig. 10 shows the complete description of RCMG-3208, which is identified as the most suitable end mill based on the criteria as set for carrying out corner rounding operation on steel and cast iron. The developed system also assists the process planner in determining the related SFM and CLT values for the considered workpiece materials.

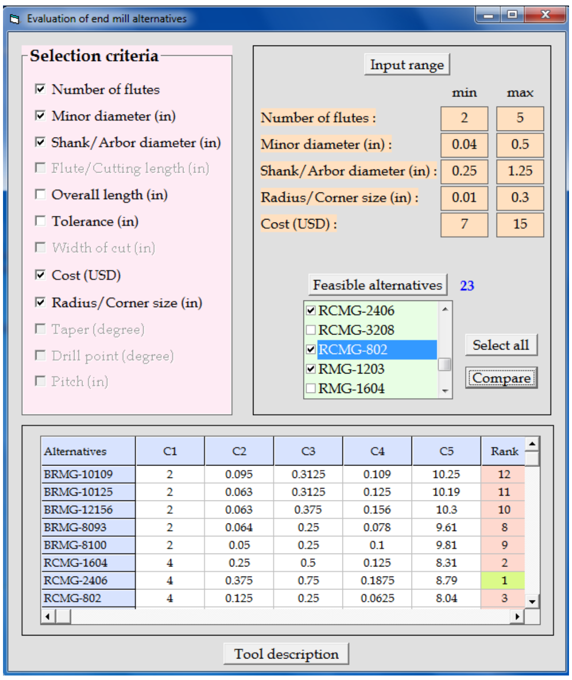


Fig. 9 Decision matrix for selection of end mill for corner rounding operation

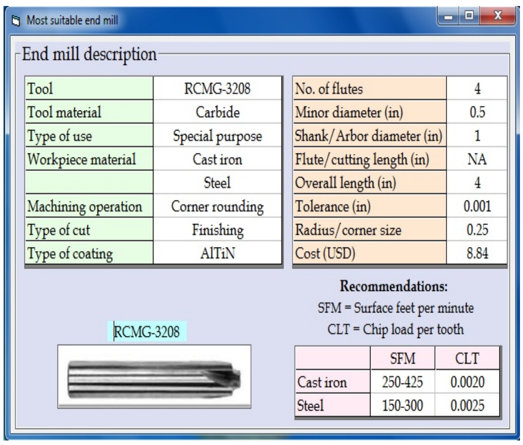


Fig. 10 Selected end mill for corner rounding operation

5. Conclusion

Technological advancements play a critical role in radical growth of the manufacturing sector. There are numerous options for end mills available with respect to their use, coating, workpiece material application etc. So, it becomes quite difficult to see and judge those alternatives one dimensionally. Moreover, this list of alternatives is growing gradually with the arrival of new commercial end mills in the market. Therefore, in this paper, a knowledge-based system is designed in Visual BASIC 6.0 which extracts the end mill alternatives from the database and compares them to identify the most appropriate end mill for a given machining application. The real time implementation of this system on a job floor considerably reduces the time required by the conventional selection procedure and minimizes human error, thus helping in better management of end mills through establishing an effective and productive work culture in the organization. Its utility and solution accuracy are also validated on a real time shop floor satisfying needs of the industrial experts. The database can be periodically upgraded with the changing business environment, thus supporting continuous improvement of the manufacturing enterprise. It ensures that quality of the highest standard is maintained throughout the production process while providing optimal ranges of values for speed and feed combination of the finally selected end mill. This system is flexible enough as it encompasses a wide range of end mill alternatives from different manufacturers into the database. Implementation of this system also results in cost minimization through reduction in manpower requirement, increased personnel efficiency and effective utilization of information. Although, it is designed and developed for an end mill selection process, it can also be employed for selection of other cutting tools, like drill bits, reamers etc. while creating a different module within the same system.

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