https://doi.org/10.20965/ijat.2011.p0655

Paper:

A Decision Support System for Capturing CNC Operator Knowledge

Wikan Sakarinto, Hiroshi Narazaki, and Keiichi Shirase

Department of Mechanical Engineering, Graduate School of Engineering, Kobe University
1-1 Rokko-dai, Kobe, Hyogo 657-8501, Japan
E-mail: 060t855t@stu.kobe-u.ac.jp

[Received February 27, 2011; accepted July 13, 2011]

The main job of Computer Numerical Control (CNC) operators is to capture and use knowledge to assess product data. CNC operators assess Computer-Aided Manufacturing (CAM) files before proceeding to CNC machining processes. Decision Support Systems (DSS), for these operators, is provided by Expert Systems (ES) designed to manage and learn inteligently from previous data and information and produce recommended actions and decisions. The purpose of the DSS is (i) to assist inexperienced operators in assessment using stored know-how of experienced operators and to collect additional knowledge in interaction between the DSS and experienced operators during semiautomatic assessment, and (ii) to present collected knowledge to users based on contexts or constraints the user must deal with in product data assessment. After outlining the DSS, the discussion is about its usefulness in dealing information and knowledge discrepancies between CAM and CNC operators – an important problem in practice that has been rather neglected so far – focusing on CNC milling operations.

Keywords: decision support system, knowledge-based system

1. Introduction

Effectively managing knowledge is critical in getting and maintaining an advantage in today's intensified competition. Knowledge is one way in which organizations improve performance, making effective information and knowledge use, reuse and handling an important issue [1].

In manufacturing, this is the case in Computer-Aided Manufacturing (CAM) and Computer Numerical Control (CNC) operations as products become increasingly complex. CAM software provides high-level assistance in generating highly accurate NC code for CNC machining and produces CAM files whose machining parameters are designed based on 3-Dimensional (3D) models created by CAD software. It also contains data on cutting tools, workpiece materials, cutting tool motion paths, etc. CAM software creates G-code [2]. If machining parameters are determined appropriately, G-code is executed on CNC equipment to produce products. Inaccurate machining parameters in Numerical Control (NC) files have expensive consequences [3] related to cutting tool cost and tool management [4].

In actual practice, however, machining parameters set by CAM operators cannot be applied to CNC machining processes due to tool wear, unavailability, or inefficiency. CNC operators or machinists must then modify those parameters before the machining process begins [3]. To avoid unwelcome repetition due to inaccurate CAM files, CNC operator knowledge should be collected, managed and shared appropriately among personnel, including CAM operators.

In previous studies [3, 4] on knowledge models for capturing a CNC operator's the knowledge and know-how, an approach has been shown how to aggregate individual case information in a consistent knowledge structure using facts based on quality, productivity, and manufacturability. Because knowledge extraction is driven by the information a CNC operator inputs, it requires substantial knowledge and labor, so the study is focused on decision support assisting CNC operators in information input. This decision support fills in information so that CNC operators can devote themselves to reviewing and modifying information presented by decision support.

Recent studies [5] briefly describe Decision-Support Systems (DSS) providing action for assisting CNC operators using this knowledge-based proposal for assessing machining parameters. This paper improves the DSS to enhance this proposal's usability by recommending new machining parameter values and by better supporting context-based information implementation supporting users in assessment [6]. Based on user-specific contexts or situations, information is stored in the database with keys accessed later through the user interface. To determine, for example, the CNC operator's perspective how to find specific machining parameters amidst constraints such as specific material to be machined applying a solid-mill finish contour at a specific Depth Of Cut (DOC). Doing so requires specific cutting tools, cost considerations less imperative than safety and manufacturability constraints, the part to be produced within a particular production number, etc. These improvements enable DSS architecture to support desired improvement targets.

This DSS proposal is closely related to Expert Systems

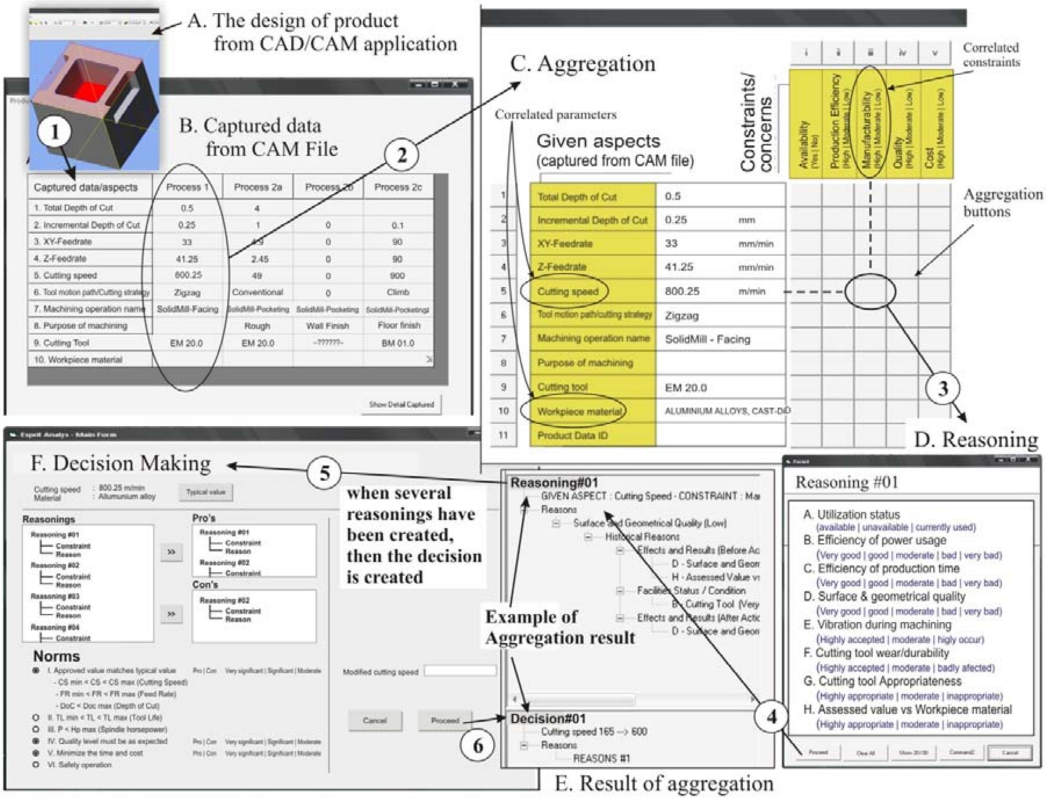

Fig. 1. Manual user interfaces flow [14].

(ESs) and Artificial Intelligence (AI) [7] targeting maximal CNC operation capture and expertise. AI, DSSs, and ES have been used in manufacturing system design such as ES for equipment selection [7], DSSs for cellular manufacturing [8], and knowledge maintenance for DSSs [9], but very rarely in CNC operator knowledge capture problems.

Section 2 discusses the proposed decision support conceptually and CNC operator decision making. Section 3 focuses on DSSs, explaining how cases are examined and treated until a decision is made, and the data structure in which associated aspects are related to connect a case to a decision. Section 3 looks at functions, mechanisms, and implementation of this proposed DSS.

2. Overview of Knowledge-Based System Design

2.1. Background

As described elsewhere for knowledge-based CAM-CNC integration design [3, 4–6], this proposal collects and manages CNC operator knowledge to share among agents in manufacturing processes. Computer programming applications embedded in CAM applications enable machining parameters and other support data to be extracted the CAM files as shown in **Fig. 1** step 1. Modules are embedded using the CAM Application Program Interface (API). Extracted data is stored and managed by the database (**Fig. 1** step 2 and after). It uses database software such as MySQL [10] and queries to construct the database [11]. This proposal shares collected knowledge with CAM users. Assessment machining parameters focused on what is commonly assessed by CNC operators in practice, e.g., cutting speed, DOC, and feed rate [12]. Queries are applied to implement ES for decision-making support. To model the decision-making flow, CommonKADS methodology [13] is used to structure knowledge to be implemented as a database.

As stated, CNC operators interact both with CNC machining processes and with proposed applications and systems, which increases their workloads. An ES proposed to assist CNC operators in information input recommends decisions on assessed machining parameters as detailed below. Decision support should have be capabilities comparable to experts. A major contribution of this paper is showing how ESs can be realized.

2.2. Decision-Making and Proposed System

In the simplest terms, CNC operators assess the appropriateness of CAM files by full acceptance, complete rejection, or conditional acceptance with some parameters modified. Key decision-making steps are as follows:

(a) Abstracting and extracting important data by checking facts such as machining parameters and standard and typical values.

(b) Evaluating whether constraints are met and explaining reasons.

(c) Making amendments and adjustments for inappropriate parameter values.

(d) Aggregating information to list norms and values to be considered in decision-making.

(e) Selecting norms such as meeting desired quality or minimizing cost and production time by considering the pros and cons before proposing a decision or recommendation.

These steps are shown using prototype screen shots in **Fig. 1**. Previous work concerned knowledge and information structures enabling these steps while CNC operators provided information manually based on the case in question. This work targets a DSS assisting CNC operators by automatically filling in and presenting knowledge-based information.

Machining parameters such as total DOC called "aspects" or given facts are extracted from CAM files as shown in step 1 (circled) in **Fig. 1**. DOC, feed rate and cutting speed are especially important aspects. The list in step 1 is called a checklist.

Given a checklist, CNC operators evaluate parameter appropriateness in evaluation called "aggregation" because, starting with the evaluation of an individual parameter, reasoning grows into a collection of pros and cons becoming the basis for modifying parameters. **Fig. 1** shows that cutting speed is judged to be "problematic" in manufacturability. Clicking on a corresponding matrix cell lists detailed viewpoints. In this example, a cutting speed of 800.25 m/min is judged undesirable because of unfavorable surface and geometrical qualities (item D in reasoning #01). In step 4, after "bad" is chosen for item D, the proceed button is clicked on and, as shown in step 5, the parameter value on cutting speed is set to be changed. After inputting modified cutting speed, a decision associated with reasoning #01 is shown in step 6, and information behind this parameter modification is recorded.

More generally, in assessing aspects and facts such as the above, a set of constraints for imposing conditions meeting major production targets is defined with a set of reasons. The five constraints in crosscutting are availability, production efficiency, manufacturability, quality and cost. "Reasons" are related to predicting what may happen given the current facts. Examples indicate whether facilities and equipment are available, whether manufacturing will be efficient, whether failures could occur, and whether quality will be as expected. Following this, norms or criteria are selected for assessing a case.

Reasoning results are classified into norm-based pros and cons. For problematic case data, CNC operators select appropriate norms from a list, classifying reasons into pros and cons. This expresses the norms causing parameter values to be appropriate, determining a truth value for the norm, e.g., "the statement that cutting speed fits the range is false." Based on this result, the next step changes the parameter, i.e., "cutting speed should be changed." In the example, cutting speed is judged to be inappropriate based on surface and geometrical quality and cutting speed should be modified based on the three norms selected in **Fig. 1** – reasoning is considered as a qualitative interpretation of the parameter value and the norm is the basis for an action such as modification.

3. DSS

Manually following the steps above is a large additional task for CNC operators. To make use easier, a DSS is added that provides guidance by arranging historical data, information and knowledge. The DSS can be viewed as an ES embedded in the main system [7], a tool to structure knowledge and organizational memory. Any ES has as its core two main types of knowledge, also called a knowledge-based system static knowledge forming the group of concepts describing the expertise in a domain and dynamic knowledge, which is the reasoning mechanism. Both are used to answer questions or to generate new facts.

3.1. DSS Design

In this study, the main concepts in static knowledge within the CNC domain are cases, machining parameters, manufacturing facilities, concerns and constraints, reasons, norms, and decisions. These are modeled using an object-oriented formalism associated with a set of attributes and methods. Objects have a hierarchy of classes and subclasses. Both attributes and methods are inheritable. The main objects for modeling domain concepts are listed in **Table 1** with their main attributes. For brevity, this table shows only objects and attributes necessary to understand the DSS working mechanism in the sections that follow.

Dynamic knowledge represented by a set of rules that control the user interface, inference and knowledge acquisition. An inference engine interprets information in the knowledge base for generating output based on conditions or situations specific to the context. For this proposal, the DSS rule base consists of inference rules incorporating rules described below. The results of inference engine and knowledge base collaboration are arranged as Expert System (ES) A, ES B, and context-based knowledge representation to be provided to users.

The first two user interface terms in **Fig. 2** are expert system A (ES A) and ES B, providing recommended actions during decision making. ES A provides recommendations based on standardized or typical data and ES B information based on historical data such as machining parameters, cutting tools used, workpiece materials machined, and associated constraints, concerns, reasons, norms and decisions made to show the percentage of alternative decisions selected in the past as detailed below. The third aspect, context-based knowledge representation, assimilates the DSS with context-based information and knowledge described elsewhere [10].

This DSS proposal is closely related to recommended actions both manually and guided as shown in **Fig. 3**. The

Table 1. Major objects and attributes.

OBJECT	ATTRIBUTES	VALUES
Machining parameter	Incremental Depth of Cut	Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5
	Number of layers of removal	Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5
	Cutting Speed	OOR-L 3 | OOR-L 2 | OOR-L 1 | Range 1 | Range 2 | Range 3 | OOR-U 1 | OOR-U 2 | OOR-U 3
	XY-Feed Rate	OOR-L 3 | OOR-L 2 | OOR-L 1 | Range 1 | Range 2 | Range 3 | OOR-U 1 | OOR-U 2 | OOR-U 3
	Z-Feed Rate	OOR-L 3 | OOR-L 2 | OOR-L 1 | Range 1 | Range 2 | Range 3 | OOR-U 1 | OOR-U 2 | OOR-U 3
	Tool Motion Path/Cutting Strategy	Zigzag | Conventional | Climb
Facilities	Workpiece Material Type	Type 1 | Type 2 | Type 3 | Type 4 | Type 5
	Workpiece Material ID	Material ID | NULL
	Cutting Tool Type	Type 1 | Type 2 | Type 3 | Type 4 | Type 5
	Cutting Tool ID	Material ID | NULL
	Cutting Tool Condition	Bad | Moderate | Good
	Machining Operation Name	SolidMill-Facing | SolidMill-Pocketing | SolidMill-Contouring | SolidMill-Drilling
	Machine ID	Machine ID | NULL
Constraint	Availability	Yes | No | NULL
	Production Efficiency	High | Moderate | Low | NULL
	Manufacturability	High | Moderate | Low | NULL
	Quality	High | Moderate | Low | NULL
	Cost	High | Moderate | Low | NULL
Reason	Utilization status	Available | Unavailable | Currently used | NULL
	Efficiency of power usage	High | Moderate | Low | NULL
	Efficiency of production time	High | Moderate | Low | NULL
	Surface & geometrical quality	High | Moderate | Low | NULL
	Vibration during machining	Highly accepted | Moderate | Highly occur
	Cutting tool wear/durability	Highly accepted | Moderate | Badly occur
	Cutting Tool Appropriateness	Highly appropriate | Moderate | Inappropriate
	Assessed Value vs Workpiece appro.	Highly appropriate | Moderate | Inappropriate
Norm	Value matches typical value	Very significant | Significant | Moderate
	Tool life optimization	Very significant | Significant | Moderate
	Power consumption optimization	Very significant | Significant | Moderate
	Quality level must be as expected	Very significant | Significant | Moderate
	Time and cost optimization	Very significant | Significant | Moderate
	Safety factor	Very significant | Significant | Moderate
Decision	DECISION	Decision 1 | Decision 2 | Decision 3 | Decision 4 | Decision 5

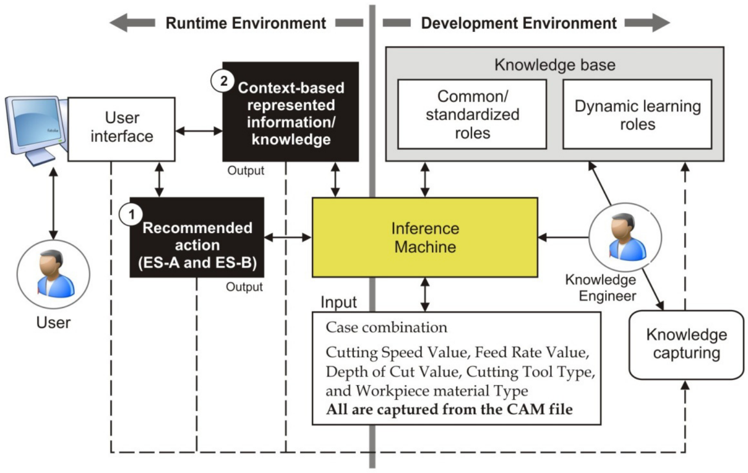

Fig. 2. DSS architecture.

manual way was shown in the previous section. For the guided way, based on data collected from CAM files, the ES automatically provides recommendations on typical or common standardized machining parameter values for the workpiece material and cutting tool used. In detail, ES B produces appropriate recommendations using past data, similar to the supervised machine learning principle [14]. Given machining parameters as input, the ES automatically draws similarities between current and past cases, predicting possible results from cases matching the current case or cases having a certain similarity as shown in **Fig. 4**. Extracting the most frequent pattern in the database deals with the combination of reason, constraint, norm and facilities associated with input. It also has to do with recommended pro and con norm and reasoning and associated facilities or equipment.

A new pattern or combination is added to the database when a user has completed a decision making procedure as shown above. Even if a case has the same pattern as a past case, the same input could lead to a different conclusion. The algorithm that the DSS follows is described below.

Step 1: Notation for objects is defined.

R_{ij} is Reason, where the type of reason $i = \{0,1,2,3,4,5,6,7\}$ and value of each reason $j =$

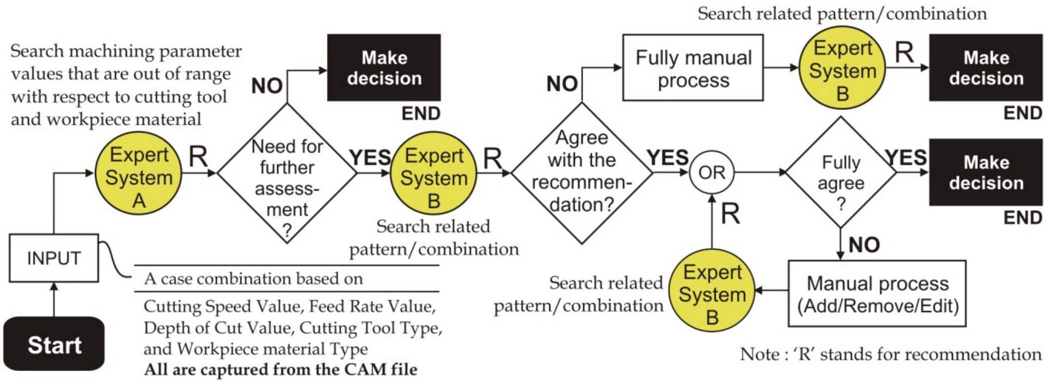

Fig. 3. Shows ES A and B providing recommended actions for decision making (R: recommendation).

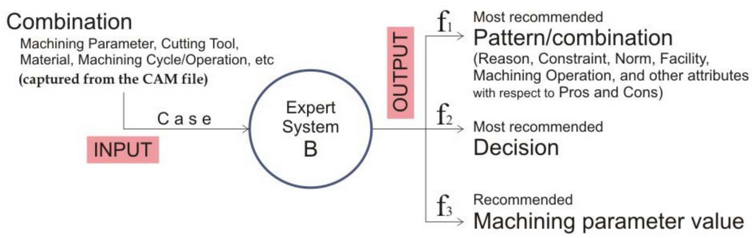

Fig. 4. ES B working mechanism as a continuation of the ES A mechanism.

$\{1,2,\ldots q\}$.

C_{kl} is Constraint, where the type of constraint $k = \{0,1,2,3,4\}$ and value of each constraint $l = \{1,2,\ldots r\}$.

N_{mn} is Norm, where the type of norm $m = \{0,1,2,3,4,5,6,7\}$ and value of each norm $n = \{1,2,\ldots s\}$.

F_{op} is Facility or equipment, where the type of facility or equipment $o = \{0,1,2,\ldots u\}$ and value of each facility or equipment $p = \{1,2,\ldots t\}$.

M_c is Material, where the type of material $c = \{0,1,2,\ldots d\}$.

CT_e is Cutting Tool, where the type of cutting tool $e = \{0,1,2,\ldots f\}$.

MP_{gg^I} is Machining Parameter, where the type of machining parameter $g = \{0,1,2,3,4\}$ and the cluster of value of machining parameter $g^I = \{0,1,2,3,4,5,6,7,8,9\}$. See **Table 1**.

MCO_h is Machining Cycle and Operation, where the type of machining cycle and operation $h = \{0,1,2,3\}$.

$Decision_q$ is Decision, where the type of material $q = \{0,1,2,3,4\}$.

$\sum Decision_q = 100\%$.

Objects in **Table 1** and correlated objects must be defined in notation similar to the above notation. For brevity, only the above objects are included for explaining the DSS working method.

Step 2: Input is defined and triggers processes within the inference engine:

I_a^b is Input leading to combination type a. b is a particular I_a.

With a set of previous input of size w and a set of combinations of size x, the set of input is:

$[I_a^1, I_a^2, \ldots I_a^w]$, where $a = (1,2,\ldots x)$ and $b = (1,2,\ldots w)$

As shown in **Fig. 4**, the combination of objects consisting of Machining Parameter (MP), material, cutting tool and machining cycle and operation generates input for the inference engine, with the following notation defined:

$$I_a^{w+1} = (MP_g, M_c, CT_e, MCO_h)$$

Step 3: ES B output, as a continuation of ES A, is defined. As shown in **Fig. 4**, which is more detailed for the end parts of **Fig. 3**, for each input I_a^{w+1}, by querying in the database, related patterns to produce recommended decisions and machining parameter values are obtained:

$$Pattern_a^{w+1} = (R_{ij}^*, C_{kl}^*, N_{mn}^*, F_{op}, M_c, CT_e, MP_g, MCO_h)$$

where:

- R_{ij}^* is the most frequent among R_{ij} for combination type a.
- C_{kl}^* is the most frequent one among C_{kl} for combination type a.

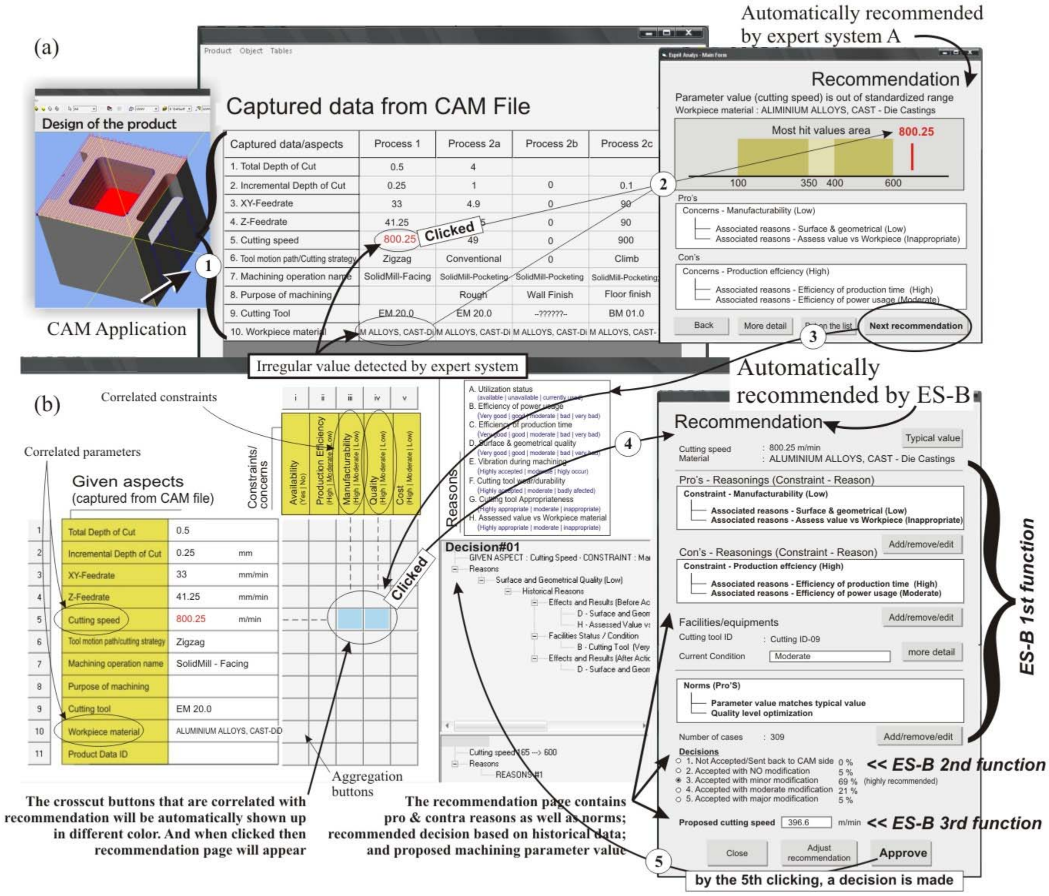

Fig. 5. Implementation of DSS for ES A and ES B.

- N^*_{mn} is the most frequent one among N_{mn} for combination type a.

The ES also delivers $Decision^*_q$, the most frequent among $Decision_q$ for combination type a.

The ES proposes the recommended machining parameter value below for combination type a. Specifically, the following formula is used within the query engine of context-based knowledge representation [14] and the third function of ES B, as shown in **Fig. 5**.

$$MP^{w+1}_g = avg \sum_{b=1}^{w} MP^b_g$$

The above steps support ES A and B for improving this proposal to make use easier and to provide arranged data and information for the query engine of context-based knowledge representation.

3.2. DSS Implementation

To show the usefulness of this proposal, a set of models with machining parameter values are prepared. During data preparation, following aspects were considered:

(i) Technical factors such as types of part and product, material, tool, and operator are considered because they are closely related to machining parameter decisions.

(ii) Different strategies for each enterprise were considered to deal with orders from customers, e.g., some enterprises tend toward quality and others toward cost efficiency.

(iii) Parts machined by conventional milling were selected. Simulation did not include all possible parts, but rather parts with similar shapes. In this case, as for each part, limitation was designed to include the number of cycles consisting of solid-mill facing, pocketing, contouring and drilling.

Based on the above considerations, 36 models were included, with an average model consisting of 12 to 20 operations. Data was collected from a small medium metal removing enterprise applying strong standards on quality and manufacturability. Although many feasible manufacturing alternatives to produce particular parts exist, it is reasonable to constrain these alternatives to those advantageous in manufacturability and quality. Generally, when speaking of shape, these models are correlated with conventional milling machining and common milling cycles such as facing, pocketing, contouring and drilling. For materials, models are mostly related to light-weight materials and mild steels.

Figure 5 shows the above formulas and the flowchart in **Fig. 3** in more detail. The ES is initiated by reading CAM data of models. The value of MP, 800.25 m/min, is recognized and assessed by ES A as OOR-U 1 – out of range

– upper 1 – or slightly above the standardized range. The DSS inference engine of the DSS, shown in **Figs. 2** and **3**, defines this condition as inappropriate and the DSS automatically generates a recommendation stating that this is a case to be dealt with as shown at right in **Fig. 5(a)**. After input is defined, ES B operates.

Based on the above, input for ES B is determined to be a combination consisting of:

- machining parameter – type 1 or cutting speed, with a value of 7 or OOR-U 1,
- material – type 9 or light material,
- cutting tool – type EM 20.0,
- machining cycle – type 1 or solid-mill facing

Based on the above, the most frequent pattern and recommended decisions are determined, and associated combination of information – reason, constraint, norm, facilities, etc. – is presented to the user as shown at right in **Fig. 5(b)**. It includes categorized pros and cons for arranging represented information. Decision lies from 0 to 4, associated with values of decisions in **Table 1**: 0 is fully rejected, 1 fully accepted, 2 accepted with minor modification, 3 accepted with moderate modification, and 4 accepted with major modification. In this example, the DSS proposes accepted with minor modification as the most recommended decision because 69% of similar past cases end up with this type of decision.

In the example above, based on the knowledge base, ES A in **Fig. 3** infers that cutting speed of 800.25 m/min is outside the typical or standardized range when the end mill cutting tool is applied to aluminum material. Following step 1 in **Fig. 5(a)**, ES A yields the recommendation shown in step 2 at right in **Fig. 5(a)**, including the pros and cons as reasons behind the recommendation. CNC operators are agreeing with this click on the "Add to List" button. As seen at right in **Fig. 5(b)**, concerns related to manufacturability and quality in dark clickable boxes are suggested. If operators agree, they click on the corresponding boxes. Each is associated with constraints and reasons, and values such as significant, very significant, low, etc. Clicking on the box displays the recommendation page as shown in **Fig. 5(b)** to specify details on concerns. On the recommendation page, ES B outputs background reasons for the recommendation such as pros, cons and facilities or equipment. This is related to function 1 of ES B. Options for the decision are listed at the bottom of the page. CNC operators agreeing then select the decision most recommended by the ES, such as accepted with minor modification in this example. ES B function 2 then takes place. CNC operators also decide on recommended machining parameter values, associated with ES B function 3. In conclusion, ES B operates by learning from previous data and information. ES A operates based on the setting of standardized range intentionally prepared prior to use.

ESs and DSSs deal with aspects of ease of use. As shown above, ESs A and B, reduce main CNC work to checking and making modifications compared to when doing above steps manually. The ES also stores and uses historical patterns to show the percentage of decisions. If a set of recommendation is totally agreed upon by the user (in this case is CNC operators), need only click five times as shown in **Fig. 5**. This set of actions is associated with ES A function and three ES B functions. Nonetheless, if a user partly disagrees with recommended actions, this proposal provides the possibility and user navigation to edit recommended actions.

4. Conclusions

The proposed novel approach implements DSS to make time in capturing CNC operator knowledge more efficient, especially in assessing machining parameters. It both decreases CNC operator task volume and assists them by providing candidates for recommended action. This DSS proposal verifies associated parameter values for regular and standardized roles, automatically recommending potential cases for standardized early verification of machining parameter values. The DSS provides recommended actions based on historical data on actions, data and information, decreasing verification and assessment time significantly. ES A and B functions are supported by implementing context-based information and knowledge [14]. The user finds data and information based on the user's specific context. The DSS implementation presented here also automatically acquires and presents context-specific knowledge documentation during the proposed application runtime. Regarding contextual information to be represented by the system, aspects or attributes in **Table 1** connected to the structure in **Fig. 2** should support context construction whenever possible. The content here focuses less on the object domain and more on supporting knowledge-intensive tasks such as decisions on manufacturing parameters. The general structure and functions for capturing and retrieving CNC operator knowledge are proposed. Functions are implemented using SQL and a relational database. After processing at the database level, data is presented at the user interface. In future, it is planned to integrate this knowledge-based application into both CAM and CNC applications. DSS aspects will be implemented in CNC operation and representation aspects of collected knowledge implemented in CAM operation. Two main reflections thus exist for future study. First is the usefulness to CAM operators in avoiding the repetition of mistake coming up with more accurate CAM files. Second, CNC operators are provided with DSS effectiveness in supporting knowledge capture and usefulness of context-based information and knowledge for the decision making.

Acknowledgements

The authors are pleased to acknowledge the support provided by the Machining Tool Technologies Research Foundation (MTTRF) in conducting this study.

References:

[1] N. Moran, "Knowledge is the key, whatever your sector," The Financial Time Limited, UK, 1999.

[2] Y. Koren, "Computer Control of Manufacturing Systems," McGraw-Hill, New York, 1983.

[3] W. Sakarinto, H. Narazaki, and K. Shirashe, "A Knowledge-based Product Model Data for Integrating CAM-CNC Operation," Proc. of The 5th Int. Conf. on Leading Edge Manufacturing in 21st Century (LEM21 2009 Osaka-Japan), 2009.

[4] W. Sakarinto, H. Narazaki, and K. Shirashe, "A Method for Capturing The Knowledge of CNC Operator for Integrating CAM-CNC Operation," Proc. of 2010 Int. Symp. on Flexible Automation (2010 ISFA Tokyo-Japan), 2010.

[5] W. Sakarinto, H. Narazaki, and K. Shirashe, "Decision Support System for CNC Machining Parameter Assessment on CNC Operator Knowledge Capturing System," Proc. of Int. Conf. on Mechatronics Technology (2010 ICMT Osaka-Japan), 2010.

[6] W. Sakarinto, H. Narazaki, and K. Shirashe, "A Knowledge-based Model for Capturing and Managing the Knowledge of CNC Operators for Integrating CAM-CNC Operation," Int. J. of Automation Technology, Vol.5, No.3, May 2011.

[7] H. Chtourou, W. Masmoudi, and A. Maalej, "An Expert System for Manufacturing Systems Machine Selection," Expert System with Application, Vol.28, pp. 461-467, 2005.

[8] L. Luong, J. He, K. Abhary, and L. Qiu, "A Decision Support System for Cellular Manufacturing System Design," Computer & Industrial Engineering, Vol.42, pp. 457-470, 2002.

[9] D. A. Guerra-Zubiaga and R. I. M. Young, "A Manufacturing Model to Enable Knowledge Maintenance in Decision Support Systems," J. of Manufacturing Systems, Vol.25, No.2, 2006.

[10] J. V. D. Bussche and A. Heuer, "Using SQL with Object Oriented database," Information Systems, Vol.18, Issue 7, pp. 461-487, 1993.

[11] J. A. Hoffer, M. B. Prescott, and F. R. McFadden, "Modern Database Management," Pearson-Prentice Hall, 2005.

[12] T. Rochim, "Klasifikasi, Proses, Gaya & Daya Pemesinan," Penerbit ITB, 1993.

[13] G. Schreiber, H. Akkermans, A. Anjewierden, R. D. Hoog, N. Shadbolt, W. V. D. Velde, and B. Wielinga, "Knowledge Engineering and Management: The CommonKADS Methodology," A Bradford Book, The MIT Press, Cambridge, Massachusetts, London, England, 2000.

[14] A. Y. Al-Qomary and M. S. Jamil, "A New Approach of Clustering-based Machine Learning Algorithm," Knowledge-bases Systems, Vol.19, pp. 248-258, 2006.

Name:
Wikan Sakarinto

Affiliation:
Ph.D. Student, Department of Mechanical Engineering, Graduate School of Engineering, Kobe University

Address:
1-1 Rokko-dai, Nada, Kobe 657-8501, Japan

Brief Biographical History:
2001- Lecturer and Researcher in Gadjah Mada University, Indonesia

Main Works:
- "A Decision Support System CNC Machining Parameter Assessment on CNC Operator Knowledge Capturing," Proc. of 14th Int. Conf. on Mechatronics Technology (2010 ICMT Osaka-Japan), 2010.
- "A Knowledge-based Model for Capturing and Managing the Knowledge of CNC Operators for Integrating CAM-CNC Operation," Int. J. of Automation Technology, Vol.5, No.4, 2011.

Membership in Academic Societies:
- The Japan Society of Mechanical Engineers (JSME)

Name:
Hiroshi Narazaki

Affiliation:
Production System Laboratory, Kobe Steel, Ltd.

Address:
5-5 Takatsukadai 1-chome, Nishi-ku, Kobe 651-2271, Japan

Brief Biographical History:
1984- Joined Kobe Steel, Ltd.
Currently, General Manager at Production Systems Lab., Kobe Steel, Ltd.
Also holds a Visiting Professor position at Graduate School of Kobe Univ.

Main Works:
Mainly engaged in the research and development activities for the application of Intelligent information technologies to production management, operation assistance, and data analysis problems.

Membership in Academic Societies:
- The Institute of Electrical and Electronics Engineers (IEEE)
- Japan Society for Fuzzy Theory and Intelligent Informatics (SOFT)
- The Institute of Systems, Control, and Information Engineers (iSCIe)

Name:
Keiichi Shirase

Affiliation:
Professor, Department of Mechanical Engineering, Graduate School of Engineering, Kobe University

Address:
1-1 Rokko-dai, Nada, Kobe 657-8501, Japan

Brief Biographical History:
1984- Research Associate, Kanazawa University
1995- Associate Professor, Kanazawa University
1996- Associate Professor, Osaka University
2003- Professor, Kobe University

Main Works:
- "Digital copy milling - autonomous milling process control without an NC program," Robotics and Computer-Integrated Manufacturing, Vol.21, Issues 4-5, pp. 312-317, Oct. 2005.

Membership in Academic Societies:
- The American Society of Mechanical Engineers (ASME)
- The Japan Society of Mechanical Engineers (JSME)
- The Japan Society for Precision Engineering (JSPE)