1P3

# Literature Database for Modellers of Machining Operations: Progress Report

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## 1. Introduction

At the meeting (of the Working Group on 'Modeling of Machining Operations' set up by STC C) held in Paris in January 1996, the author volunteered to develop a literature database focused on "Modeling of Machining Operations" as a part of the activities of the group. This paper reports on the current status of the database development activity.

The work on the database was started almost immediately after the January 1996 meeting. The first phase was devoted to searching for a database software which facilitated the achievement of the following goals:

1. Provide a PC-based environment which can be progressively upgraded to keep up with the rapid changes that are occurring in the field of computer software and databases.
2. Enable the recording of optional comments and 'labels' in addition to basic bibliographic data.
3. Support the creation and maintenance of a database of a size sufficient for the requirements of modellers of machining operations (a few thousand records).
4. Enable the periodic importation of data collected from different individuals (mainly CIRP members) into the main database without corrupting it.

However, despite help from some CIRP colleagues and others, the author could not locate and acquire a software that facilitated the achievement of all the goals (in particular, goals 2 and 3 could not be met). Hence, a decision was made to develop a new software to support the present project.

Two verbal reports on the progress of the database software have already been made — one at the August 1996 (Como) meeting and the other at the January 1997 meeting (at Paris, by Dr. Alexander Djordjevich of City University of Hong Kong) of the Working Group.

The author is happy to report that the software is now operational (at least to the extent of being able to input data and retrieve it for analysis) and that data related to 2801 papers has been input into the database. The following sections describe the system and analyze the data collected so far.

## 2. The LTS Software

The Literature Tracking System (LTS) has been written in Microsoft Visual Basic (version 2.1). The database itself is a FoxPro 2.5 database. Hence, the database can be manipulated by using Microsoft Access. Although there are some limited reporting features embedded within LTS, more extensive analysis (utilizing SQL based queries) and reporting can be achieved through Access. Alternatively, one could utilize the Crystal Reports package. Efforts are in progress to upgrade the software to version 5 of Visual Basic. LTS can be used within Microsoft Windows version 3.1 or Windows 95.

## 3. LTS Menu

LTS includes the following menu items:

- File
  - ... New (input a new article)
  - ... Open (open an article for editing)
  - ... Delete (delete an article)
  - ... Import (import data from a drive)
  - ... Export (export data to a drive)
  - ... Exit
- Set Up (only by the originator of each LTS application)
  - ...Labels and Classes
  - ...Journals (standardized titles)
- Report
  - ... All
    - ... Without Labels, etc.
    - ... With Labels, etc.
  - ... By Selected Author
  - ... By Selected Labels
  - ... Selected Articles
- Zap (Delete all data)

At the moment of writing this report, only 'File' and 'Set Up' are fully functional.

When the user chooses 'Open' or 'Delete', LTS displays the first author name and the title for all articles in the database. For convenience, the articles are automatically sorted in the ascending alphabetical order of the first author's name.

Although LTS has been mainly developed for the purposes of the Working Group, it can also be used for supporting other literature review applications. All one needs to do is to make a copy of the current database, 'zap' all data from it, appropriately rename it, and set up the labels suited for the new application.

When a set of articles is 'imported' LTS begins by importing the data for each article and matches it with each existing article in the database. If there is no match, the full information associated with the article is appended. If there is a match only the extra information contained (if any) is imported.

The 'Import' and 'export' features, when taken together, provide a powerful means of progressively expanding the database by merging information obtained through group effort.

## 4. LTS Database Fields

LTS enables the recording of the following information related to each article: title, author names (up to five authors), the month and year of publication, the name of the journal/conference/..., the name of the publisher, the location of the conference/publisher, the edition number, the volume number, the issue number, the numbers of the starting and end pages, and the abstract. The user enters only the data items available. However, a title and the first author's name must always be entered in order to maintain the integrity of the database. In addition, LTS enables the inclusion of 'comments' and 'labels' fields.

The 'comments' field represents one value adding feature of LTS. 'Comments' provides a useful way of recording the user's personal thoughts within the database. The comments could be "I must get and read this paper for my project.", "I must ask Mr. X, my PHD student, to read this.", "This paper reaches a conclusion which is opposite to that stated by Mr. Y in paper Z.", etc.

The most significant and value-adding feature of LTS is that it enables the inclusion of 'labels' within article data. A 'label' is a descriptor of the article from a specific point of view. The set up menu permits the user to customize the labels, i.e. it permits only those labels which are decided *a priori* on the basis of a careful analysis of the context and purpose of the database.

## 5. Articles and Labels Included in MMO-LTSDB

As mentioned earlier, "Modeling of Machining Operations: Literature Tracking System Data Base (MMO-LTSDB)' presently contains information on 2801 articles. The articles to be included were selected on the basis of the following considerations:

- Articles appearing to be directed at developing, validating, or discussing models for machining with defined cutting edges irrespective of whether the models are predictive or non-predictive.
- Articles of interest to modellers: Modellers are basically driven by the need to explain or predict experimentally discovered magnitudes of measured parameter, parameter trends, and phenomena. Hence all articles which throw some light on such issues are of interest to modellers. Likewise, information on the instruments, equipment, techniques or methodology used in experimentation is also useful.
- Landmark articles which contain some fundamental principles (drawn from more basic sciences such as Solid Mechanics, Heat Transfer, and Tribology) and frequently referred to in machining literature.
- Articles related to sensing, monitoring, compensation, etc.: One of the messages emerging from the Working Group is the need to bring the worlds of modeling and sensing together.

Tables 3 to 15 show the labels currently set up in MMO-LTSDB. The titles of the tables indicate the label classes. The considerations behind the selection of these labels are contained in the paper [1] presented by the author to the Working Group in its January 1996 (Paris) meeting. Subsequently, at the August 1996 (Como) meeting, these labels were discussed broadly and endorsed by the Working Group.

## 6. Observations and Discussion

The present contents of MMO-LTSMDB has been 'queried' in different ways using Microsoft Access Version 7.0. The results are listed in Tables 1 to 15. While there must be some bias arising from the author's background in the selection of the articles, many of the observations, when expressed as percentage of total number of papers, are quite likely to be of universal interest and do throw some light on the status of machining literature. Some such observations are highlighted below.

- Table 1 indicates that the rate of publications has significantly increased since the mid eighties.
- Table 2 indicates that milling, classical operations, turning, and drilling (in that order) are the operations that have attracted most attention. Surprisingly, there is significant interest in rotary cutting although its application in industry is relatively rare. This may be because the rotary process is associated with several features of interest to modellers: e.g. chip length can be larger than cut length. In contrast, more practical operations like gear cutting, sawing, broaching and tapping have attracted very little attention.
- Table 3 indicates that, within the field of milling, end mills have attracted more interest possibly because of their extensive use in machining centers.
- Table 4 indicates that the progress of machining science has not been dramatic despite its history of over 50 years and the efforts put in by a large number Of scientists. Notwithstanding the availability of powerful computers which can be used to analyze more complex operations, significant interest still persists in the relatively simpler case of single edge orthogonal cutting. It might be that many theoretical concepts can be tested more easily on orthogonal cutting. However, as long as the modellers do not progress well beyond single edge orthogonal cutting, they would have little impact on industrial practice.
- Table 5 indicates that modellers continue to be disinterested in many important turning operations such as taper turning, grooving, parting (a difficult operation), and thread cutting
- Table 6 indicates that many drill forms have hardly been studied although they are being increasingly used in industry.
- Table 7 indicates that, amongst the various modes of rotary cutting, the self propelled mode is the most prominent. Industrial practice of rotary cutting, to the extent it is applied, is confined to the self propelled mode.
- Table 8 shows that there is significant interest in sensing and monitoring. A more detailed study of the database has shown that much of this interest has appeared since the mid eighties and that the sensing techniques have generally been augmented by Artificial Neural Nets and such AI-based techniques. On occasion, there has been a model-based processing of sensory data.
- Table 9 shows that very little work has been done in studying (leave alone modeling) machining with non-plane rake faces although the vast majority of modern tools have complex rake faces. This is another reason why modeling has not moved out of the laboratory (or the computer room in these days) and into the shop floor.
- Table 10 shows that there is a significant and growing interest in ceramic tools, machining hard materials, and high speed cutting. Much of this interest seems to be industry inspired. That is good news. The bad news is that much of this work is experimental or phenomenological and there has been very little modeling work in these areas. Table 10 also indicates that hot or cryogenic machining, and oscillatory machining, which at one time were of some interest, are now fading out.
- Table 11 indicates that analytical modeling continues to dominate the modeling scene. However, there is growing interest in Finite Element Modeling in recent years. That is good news. The bad news is that, except in the rare cases when the models are supported by custom-built machining databases, these models can still only predict qualitative trends. Their performance with regard to quantitative prediction continues to be questionable — another reason for the lack of impact on industry.
- Table 12 indicates that acoustic emission has emerged as the predominant sensing technique in on-line process monitoring. The next item in this table is "dynamometer" which appears to have been inspired by the needs of experimenters rather than on-line monitoring.
- Table 13 identifies the degree of interest in the various aspects of the machining process. Many trends are easily identifiable from the table. It seems that the study or modeling of cutting forces, tool wear, work material effects and cutting

temperatures have attracted the greatest attention (in that order). However, it must be noted that this table does not tell the whole story since, in the present database, labeling was done only on the basis of an interpretation of the article title. More accurate and detailed labeling would have required the author to read each and every article fully and appreciate its scope! This is where collaborative work (as exemplified by this Working Group) becomes useful. It is desirable that 'labels' gathered from different discerning readers be pooled.

- Table 14 shows that 'Annals of CIRP' has contributed significantly to machining literature.
- Table 15 shows that USA. Japan, UK, Australia, USSR (former name), India and Canada (in that order) have contributed significantly to machining literature. Other contributors to the field include Hong Kong (now a Special Administrative Region of China), Italy, Sweden, Israel, Netherlands, China , France, Taiwan and Greece (and Belgium?). Most other countries have made negligible contributions.

### 7. **Future Work on MMO-LTSDB**

- Increase the number of articles, say, by 1000.
- Refine the list of labels.
- Label articles to a deeper level through group effort amongst the Working Group members.
- Analyze the database using multi-level queries.
- Distribute copies of database within CIRP.

Place the database on the Internet and periodically update the database through group effort.

### 7. Concluding Remarks

The above discussion does not paint an encouraging picture of the current state of modeling of machining operations. There is indeed a wealth of knowledge concerning machining. It is generally agreed that this knowledge is quite useful for process designers. The models so far created have been quite successful in qualitative predictions. However, it is a different story when it comes to quantitative prediction. No wonder then that there have been very few automated industrial machining systems where a modeling package is a regular and critical component of the system control software.

Given the above discouraging observation, it was surprising to see recently the following sentences in a news brief included in the 'Manufacturing Engineering' journal published by SME: "A metal cutting FE modeling software called Mach2D to be released by Third Wave to be realized in 1997. Capable of modeling forces, temperatures, material removal rate, chip growth, chip breaking, chatter, and vibration." [2]. Is this true? Can we believe it? If this news item is indeed credible, we do not need this working group since it's dream would have aready been realized!!!

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### References

1. Armarego, E.J.A., Jawahir, I.S., Ostafiev, V.A., and Venuvinod, Patri K., "Modeling of Machining Operations," Paper presented at the meeting of the Working Group on Machining Operations of STC C of CIRP, Paris, January 1996.
2. Anonymous, "Model Your Metal Cutting," Manufacturing Engineering, SME, May 1997, p. 48.

**Table 1: Historical Trend (Total 2801)**

| Label | Article Count |
|---|---|
| Unidentified | 37 |
| Up to 1930 | 41 |
| 1931-35 | 22 |
| 1936-40 | 22 |
| 1941-45 | 29 |
| 1946-50 | 46 |
| 1951-55 | 109 |
| 1956-60 | 168 |
| 1961-65 | 235 |
| 1966-70 | 290 |
| 1971-75 | 136 |
| 1976-80 | 228 |
| 1981-85 | 348 |
| 1986-90 | 379 |
| 1991-95 | 560 |
| 1995-97 | 151 |

**Table 2: Class of Machining Operation (Total = 2801)**

| Label | Article Count |
|---|---|
| Milling | 314 |
| Classical | 274 |
| Turning | 212 |
| Drilling | 192 |
| Rotary | 75 |
| Boring | 30 |
| Other | 28 |
| Gear Cutting | 20 |
| Sawing | 9 |
| Broaching | 6 |
| Tapping | 2 |
| Reaming | 2 |
| Skiving | 0 |

**Table 3: Milling (Total = 314)**

| Label | Article Count |
|---|---|
| Milling (General) | 145 |
| End Mill | 75 |
| Face Mill | 47 |
| Plain Peripheral Mill | 31 |
| Ball End Mill | 15 |
| Turn-Mill | 4 |
| Slab Peripheral Mill | 0 |
| Form Mill | 0 |

**Table 4: Classical Machining Operation (Total 274)**

| Label | Article Count |
|---|---|
| Single Edge Orthogonal | 207 |
| Single Edge Oblique | 81 |
| Two Edge Orthogonal | * |
| Two Edge Oblique | * |
| Multiple Edge | * |
| Form Cutting | * |

* Unable to report because of data corruption encountered while running LTS

**Table 5: Turning (Total = 212)**

| Label | Article Count |
|---|---|
| Turning (General) | 170 |
| Facing | 14 |
| Cylindrical Turning | 9 |
| Taper Turning | 1 |
| Grooving | 0 |
| Paring | 0 |
| Thread Cutting | 0 |

**Table 6: Drilling (Total = 192)**

| Label | Article Count |
|---|---|
| Drilling (General) | 129 |
| Standard Twist Drill | 35 |
| Modified Twist Drill | 16 |
| Gun Drill (including Qun Drill and Deep Hole Drill) | 6 |
| Facet Point Drill | 4 |
| Hosoi Point Drill | 2 |
| Long Series Drill | 2 |
| Modified Corner Drill | 1 |
| Prismatic Drill | 0 |
| Rounded Corner Drill | 0 |
| Spade Drill | 0 |
| Special Twist Drill | 0 |
| Spiral Point Drill | 0 |
| Crank Shaft Drill | 0 |
| Stepped Drill | 0 |

**Table 7: Rotary Cutting (Total = 75)**

| Label | Article Count |
|---|---|
| Self Propelled Rotary | 37 |
| Rotary (General) | 31 |
| Driven Rotary | 8 |
| Rotary Oblique | 3 |
| Rotary Orthogonal | 1 |
| Rotary Milling | 1 |
| Rotary Shaping | 0 |
| Rotary Turning | 0 |

**Table 8: Type of Contribution (Total = 2801)**

| Label | Article Count |
|---|---|
| Sensing (including Measment, monitoring and compensation) | 231 |
| Experimental | 226 |
| Predictive Modeling | 163 |
| Appraisal/Overview | 132 |
| Instrumentation/Equipment | 101 |
| Control ((including adaptive and machine control) | 76 |
| Optimization/Economics | 58 |
| Phenomenological | 42 |
| Simulation (computerized) | 33 |
| About Modeling | 2 |

**Table 9: Nature of Rake Face (Total = 2801)**

| Label | Article Count |
|---|---|
| Controlled Contact | 38 |
| Grooved | 12 |
| Obstruction Type Chip Former | 5 |
| Complex Chip Former | 1 |

**Table 10: Nature of Process (Total = 2801)**

| Label | Article Count |
|---|---|
| Ceramic Tools | 82 |
| Machining hard, Difficult, and Space Age Materials | 78 |
| High Speed Cutting | 70 |
| Coatings on Tools | 57 |
| 3-D process, analysis, or model | 49 |
| Intermittent Cutting | 27 |
| Finish Machining | 24 |
| Precision Machining | 17 |
| Hot Machining | 13 |
| Use of Coolant Jets | 13 |
| Dry Machining | 1 |
| Cryogenic Machining | 1 |
| Oscillatory Machining | 0 |

**Table 11: Modeling Approach (Total = 2801)**

| Label | Article Count |
|---|---|
| Analytical or Mathematical | 333 |
| Finite Element | 83 |
| Artificial Neural Net | 32 |
| Statistically Fitted | 31 |
| Semi-Empirical | 23 |
| Probabilistic or Stochastic | 14 |
| Fuzzy Logic Based | 8 |
| Boundary Element | 4 |
| Chaos or Fractal Theory Based | 3 |
| Finite Difference | 2 |
| Knowledge Based | 0 |
| Other | 0 |

**Table 12: Sensing Method (Total =334)**

| Label | Article Count |
|---|---|
| Acoustic Emission | 71 |
| Measurement of Forces (Dynamometer Design) | 38 |
| Computer Vision | 6 |
| Radiation Measurement | 6 |
| Metallography | 4 |
| Cinematography (Movie) | 3 |
| Scanning Electron Microscope, etc. | 3 |
| Workpiece Deflection Measurement | 0 |
| Workpiece Dimensional Measurement | 0 |
| Vibration Measurement | 0 |
| Sound or Noise Measmnt. | 0 |
| Temperature Meaurement | 0 |

**Table 13: Aspect Studied (Total = 2801)**

| **Label** | **Article Count** |
|---|---|
| Forces | 391 |
| Tool Wear | 363 |
| Work/Tool Material Related Effects | 244 |
| Temperatures | 241 |
| Dynamics (including vibration and transient effects) | 111 |
| Chip Formation | 140 |
| Tool Life | 120 |
| Tool Geometry (including Tool Grinding) | 112 |
| Tool Fracture | 96 |
| Chip Breaking (including Chip Control) | 73 |
| Stresses (including stresses in chip formation zone and Tool) | 68 |
| Friction (including Chip/Tool Contact State) | 61 |
| Shear (including Shear Plane/Zone) | 57 |
| Shear Angle | 53 |
| Surface Roughness/Finish | 53 |
| Machinability | 51 |
| Chip Curl (including Chip Form) | 45 |
| Cutting Fluid and its Action | 43 |
| Workpiece Accuracy | 39 |
| Work Hardening (including Cold Working of Machined Surface) | 35 |
| Built-up-Edge/Layer | 33 |
| Strains (including strain rate effects) | 31 |
| Surface Integrity | 28 |
| Cut Geometry | 27 |
| Serrated Chips | 26 |
| Tool Materials | 25 |
| Chip Flow Angle | 23 |
| Residual Stresses | 21 |
| Plasticity Condition | 19 |
| Diffusion Wear | 14 |
| Discontinuous Chip Formation | 10 |
| Slip Line Fields | 9 |
| Plowing (Cutting Edge Sharpness Effects) | 9 |
| Groove Wear | 7 |
| Force Partitioning Between Cutting Edges | 3 |
| Abrasive Wear | * |
| Adhesion Wear | * |
| Burr Formation | * |
| Chemical Wear | * |

**Table 14: Publication Medium (Total = 2801)**

| Label | Article Count |
|---|---|
| Annals of CIRP | 232 |
| PhD Thesis | 199 |
| Book (including Standard) | 110 |
| Report | 53 |
| Master's Thesis | 36 |
| Book Chapter | 26 |
| CIRP Symposium/Meeting | 21 |
| Other (Patent, etc.) | 7 |

**Table 15: Country of Origin (Total = 2801)**

| Name | Art. Ct. | Name | Art. Ct. |
|---|---|---|---|
| USA | 889 | Yugoslav | 6 |
| Japan | 245 | Egypt | 4 |
| UK | 201 | Korea | 3 |
| Australia | 196 | Georgia | 3 |
| Germany | 180 | Spain | 3 |
| USSR | 178 | Ukraine | 2 |
| India | 151 | Czech | 2 |
| Canada | 85 | Finland | 2 |
| Hong Kong | 46 | Norway | 1 |
| Italy | 36 | Rumania | 1 |
| Sweden | 30 | S. Africa | 0 |
| Israel | 29 | Pakistan | 0 |
| Netherlands | 28 | Malaysia | 0 |
| China | 25 | Hungary | 0 |
| France | 24 | Mexico | 0 |
| Taiwan | 21 | Iran | 0 |
| Greece | 20 | Indonesia | 0 |
| Denmark | 11 | Rumania | 0 |
| Singapore | 10 | Turkey | 0 |
| Poland | 7 | Belgium | * |