An Interdisciplinary Problem Solving Approach to Company Integration

IONEL BOTEF and BARRY DWOLATZKY
School of Mechanical, Industrial, and Aeronautical Engineering
University of the Witwatersrand, Johannesburg
1 Jan Smuts Avenue, Johannesburg
SOUTH AFRICA
http://www.wits.ac.za

Abstract: - Studies have shown that the classical techniques do not result in a total computer aided process planning (CAPP) system. Therefore, we are proposing a collaborative and interdisciplinary problem solving CAPP architecture that can be expected, over time, shift toward and expand the notion of information technology (IT) infrastructure, and consequently become a mechanism for company integration. The architecture offers simplicity, computability, reusability, and improved communication. All these in turn is inspected to facilitate new developments in fields such as process control at high and low CAPP levels, semi-automated man-machine interfaces capable of better supporting the human operator, and promote technology transfer, education, and training.

Key-Words: - Information Systems, CAPP, Software for Manufacturing

1 Introduction

Productivity in the manufacturing industry has increased substantially over the past decade through automation and robotics, supported by IT, new manufacturing processes, and new ways of doing business. However, in today's competitive world, the interrelated trends in technology, system requirements, and economics are creating a new environment that challenges the limits of traditional engineering approaches, drawing in this way the attention to the need for radical new approach [1]. In addition, these challenges necessitate that many more disciplines need to be involved in understanding, collaborating, and implementing the changes in manufacturing that will bring substantial business improvement in the new millennium.

In these conditions, despite that more complex manufacturing processes and leaner production strategies have been implemented in manufacturing companies, it has been the architecture design and implementation which made these companies incapable of rapidly responding to changes, perform less than required, and becoming an impediment within a production facility [2].

Considering above circumstances, we suggest that the benefits that can accrue from introducing flexible automation should not be confined to the manufacturing operations alone, but wider issues must be considered such as product design, production control, education and training, and process planning. With these in mind, the paper proposes a CAPP architecture that can be expected, over time, shift toward and expand the notion of IT infrastructure to include business applications such as CAPP that can thus become a mechanism for company integration.

The paper is organised as follows: section 2 defines the general environment that motivated the new CAPP software development process. Section 3 contains the general research guidelines, and the description of the system architecture. This architecture is then analysed alongside CAPP trends and research recommendations found in the literature, and conclusions are drawn in section 4.

2 Research Motivation

Process planning is defined as the activity that establishes the process that transforms the raw material into the desired final part [3], or the transformation of detailed engineering drawings specifications into operating instructions [4].

CAPP is the term used for automated approaches to developing process plans from an engineering drawing. The planning approach, itself, the data and knowledge used, the modeling and analysis techniques all determine whether process planning may be called variant, semi-generative, or generative [5]. In the variant approach, for new components, process plans are based on existing plans which are retrieved and modified. In the generative approach, for new components, the process plans are generated automatically without reference to the existing plans.

Process planning and CAPP are developed within the limitations imposed by several factors such as:

- Product configuration, available processes and equipment, production capacity, existing knowledge, and company organisation.
- Inherent instability of the processes, mixture of continuous and batch operations, incomplete and/or excessive data, changed processes, or temporal problems [6].
- Shift in manufacturing paradigm from an economy of scale to an economy of information, flexibility, and intelligent systems [7].

Since process-planning activities are highly knowledge intensive, complex and dynamic in nature, artificial intelligence based techniques have been the major technology components involved in CAPP. During the past years, various techniques were used, such as knowledge-based systems (KBS), case-based reasoning (CBR) system, or hybrid systems that combine, for example, expert systems and neural networks (NNs) [8]. However, although the introduction of artificial intelligence (AI) has boosted both the interests in the problem and the capability of the CAPP systems, the results are still far from desirable [9]. CAPP systems in the real world are usually large and complex [10], and despite the importance of CAPP there have been few reports about the use of automated process planning in industrial companies [3]. Engineering designers' tools have proven very useful while automated process planning tools have not emerged after 17+ years of study [11]. CAPP is one of the main unresolved problems of manufacturing engineering [12]. Research carried out during the last twenty years has shown that the classical techniques do not result in a total CAPP system, therefore, it is necessary to look for distinctly new approaches to solve the CAPP problem [13]. In these conditions, a very important question is why CAPP has not been successful after so many years of research. In an attempt to answer this, we briefly present some of our findings which should not be considered as a complete list, and that refer to:

- Part representation
- CAPP automation projects
- User acceptance

The part representation evolved from wire modeling, to surface modeling, to solid modeling, and to feature modeling. This evolution has been, to a certain extend, an attempt to a smooth transition from design to computer aided manufacturing (CAM). In this respect, a success example is the computer numerical control (CNC) software packages that offer today increasingly sophisticated features. The CAPP instead, 'trapped' between design and manufacturing, has many shortcomings. Some of the main reasons for this refer to the methods of the product representation [14] and the lack of the associated reasoning schemes for the identification of operation sequences [12]. We are bringing in discussion two examples.

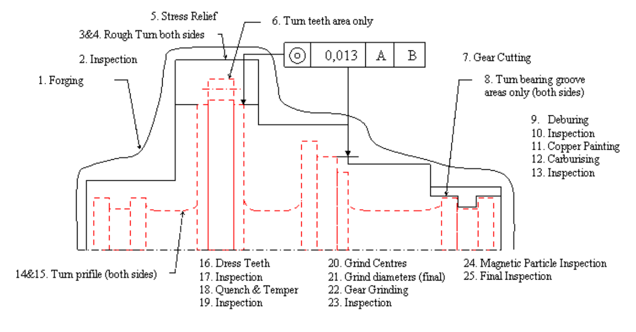


Figure 1. Typical gear-shaft in aerospace engines

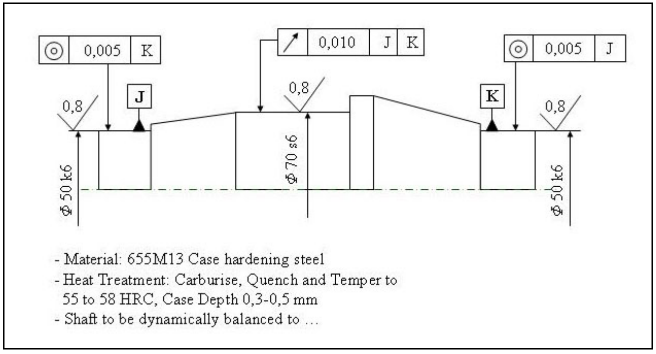


Figure 2. Medium speed shaft

For example in Figure 1, the condition of concentricity between the peach circle diameter of the gear relative to datum 'A' and 'B' must be correlated with manufacturing technological feature not represented in the engineering drawing, and therefore 'hidden' to a feature extraction mechanism. In Figure 2 the setback is how a well designed drawing can be optimized from manufacturing perspectives? We consider this an important question because the process planner, therefore CAPP system, must not be a 'blind' interpreter of an engineering drawing.

In this paper we do not attempt to find answers to these shortcomings, but we consider that the actual techniques for design-CAPP integration are inadequate therefore, radical new approaches are needed.

Another reason for CAPP failure is the way of approaching CAPP projects. CAPP is an automated approach to developing process plans from an engineering drawing. This means that when developing a CAPP system, in fact we are involved in an automation project. Such projects instead use well-known principles such as the USA (Understand Simplify Automate) principle, the ten strategies for automation and production systems, or automation migration strategy [15]. For example, the USA approach is so general that it is applicable to nearly any automation project. Our findings indicate that the 'Simplify' component has been neglected in the vast majority of CAPP developments found in literature, and therefore a possible cause of its shortcomings.

Last finding presented here is related to the user acceptance. Research has indicated that the technological choices will affect the workplace [16] and that successful manufacturing system models used human-machine interfaces that enabled individuals to interact with the modes for learning, planning, and manufacturing control [17]. In the CAPP case, the technology choice in many projects is to give cutting parameters to the machining operator. But, as Figure 3 emphasises, CAPP's most efficient area uses the most skilled operator that knows or makes use of the most up to date knowledge and cutting tools. As the CAPP software maintenance does not reflect such recent technology, the operators will critically analyse the CAPP data and therefore possibly reject it.

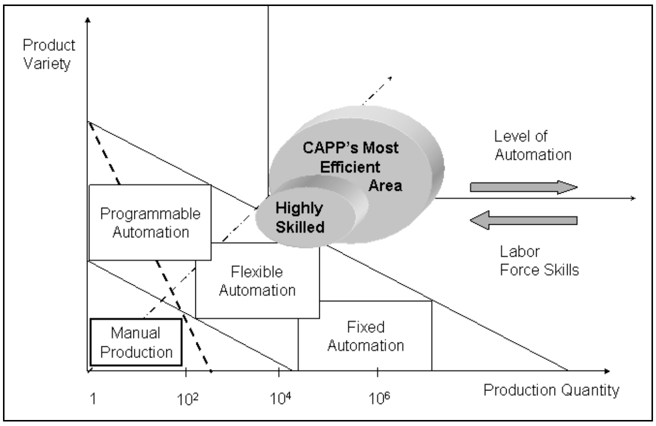


Figure 3. Levels of automation and people skills

So far in this section we presented the environment motivation that determined a new CAPP software development. In the next section we are going to briefly present our CAPP approach.

3 An Interdisciplinary Solution

Among the many approaches to improve the product development process, the introduction of new software solutions to support process activities has been reported as offering the best positive impact [3]. However, the software development should balance and limit its reach at any given point in time to the realities that technologies, tools, people, and organisational patterns permit [18]. Consequently, a new CAPP is not just a technical development of a complex software system, but important social, organizational, managerial, and business implications must be considered. Getting these factors wrong can doom the best technical effort [19]. In this context, we are introducing the SACAPP (South African CAPP) system currently in development at the University of the Witwatersrand, Johannesburg.

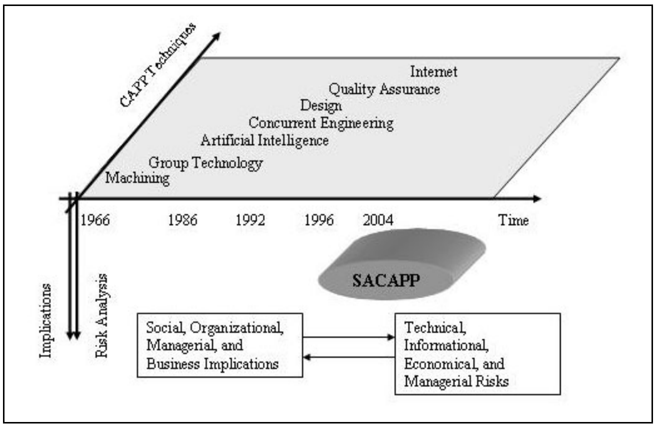


Figure 4. CAPP diversification and SACAPP

As Figure 4 indicates, SACAPP is a natural CAPP evolution from work on specific parts of manufacturing systems such as machining (M) or group technology (GT), to techniques that strongly emphasised the whole manufacturing system, such as design and product control, to new dimensions that involves social, organizational, managerial, and business implications.

In order to support SACAPP development, a number of principles are applied such as:

- The "closed loop" principle
- Simplifying complexity
- Iterative and architectural centric software development process

The “closed loop” principle states that information systems should be designed such that those who provide input to the system are also main users of its output, and that local data collection should be for local use [20]. Application of this principle results in feedback to the supplier of data, who is thereby forced to provide accurate input. It also prevents users from asking more than they need. SACAPP will apply this principle at all levels of its development. For example at machine level (see Figure 5), independent automated modules will make use of various techniques such as neural networks for the selection of process parameters, information and training. Other features should include tolerance calculations or machine-tool setups.

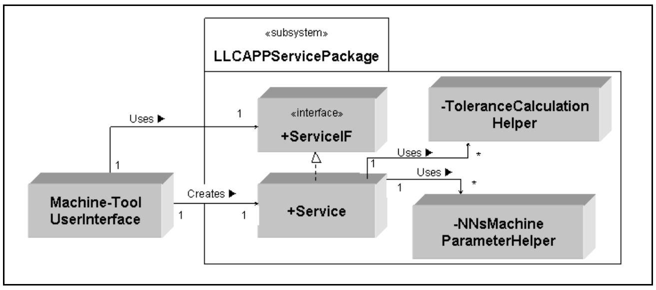


Figure 5. SACAPP at machine level

By applying the ‘simplifying complexity’ principle, we are in consent with USA principle discussed above, but also with the natural way people use only a few simple tools to understand and manage the complexity of the everyday life [21]. This approach is essential in aiming to find ways to avoid, or at least to mitigate, the spiralling complexity and by making humans and automata real partners with shared goals and a mutual understanding of each other’s capabilities and limitations [22]. However, the main obstacle to the widespread implementation of such principles is the resistance to changing the paradigm that says complex systems require complex systems to manage them [23].

SACAPP applies the simplifying complexity principle in various forms and at various activity levels. For example, the design interpretation for developing the manufacturing operation sequence list is made in the same way as the human process planner thinks; this is, by developing and using manufacturing features objects. For operations that require CNC machining, commercial-off-the-shelf software packages such as EdgeCAM are used. The company information flow is partitioned and the ‘closed-loop’ principle is applied as far as possible. The information between various levels represents the essential information required, and usually presented in graphical format.

The SACAPP development also follows the unified software development process using Unified Modeling Language (UML) when preparing all blueprints of the software system. SACAPP gives UML’s three key concepts - use-case driven, architecture-centric, and iterative and incremental development, equal importance. A use-case is a piece of functionality in the system that gives a user a result of value. The architecture provides the structure in which to guide the work in the iterations, whereas use cases define the goals and drives the work through iteration. We need the system architecture in order to understand the system, organize development, foster reuse, and evolve the system. However, the architecture is influenced by many other factors such as: customer requirements, experience and knowledge, system software and middleware products, legacy systems, standards and policies, or distribution needs. A list of candidate requirements for the new system includes items such as platform independent open and flexible system, operating in a client server environment, with commercial off-the-shelf core features and functionalities that can be configured to allow the full expression of company business rules and practices, and a smooth transition during implementation.

Considering all the above, we present in Figure 6 our view of the basic components of an intelligent manufacturing system with SACAPP as an integrated system.

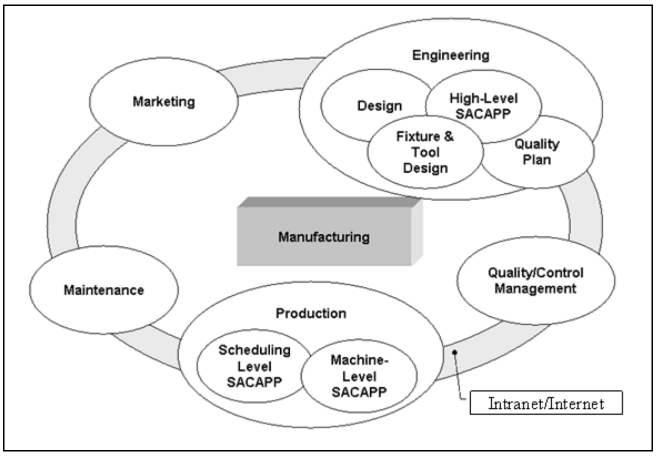


Figure 6. SACAPP components

The high-level SACAPP is part of the engineering pack management subsystem (EPMS) and is an extension of the intelligent design subsystem. The EPMS must support a progressive and real automation of engineering processes such as design, process planning operations sequence list, manufacturing technological drawings (TD), fixture and tool design, and when required, the issue of the quality assurance plans.

Considering the above, Figure 7 defines the general SACAPP architecture and functionality of the proposed system, in which time Figure 8 shows a view of its Unified Modeling Language (UML) representation.

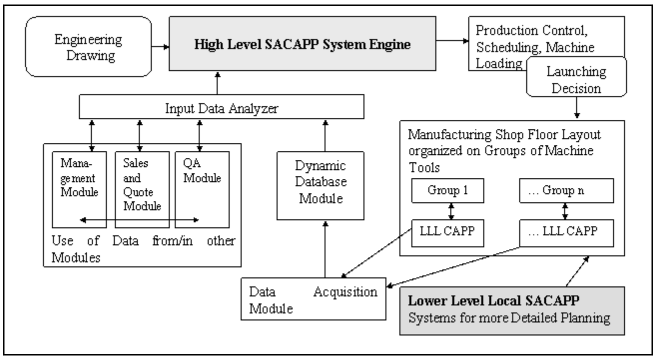


Figure 7. SACAPP architecture

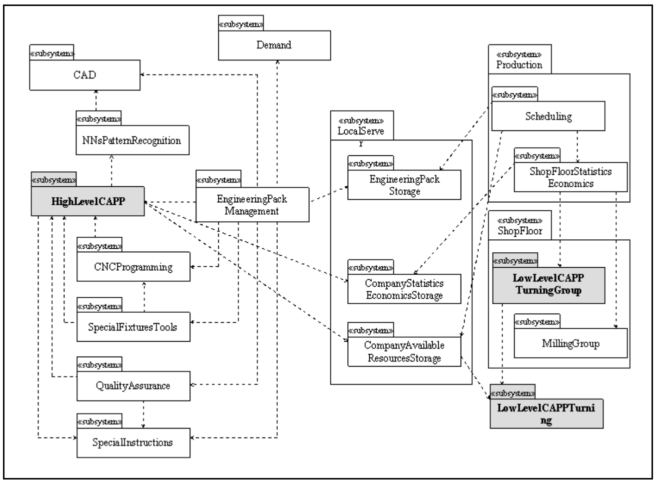


Figure 8. SACAPP architecture with UML

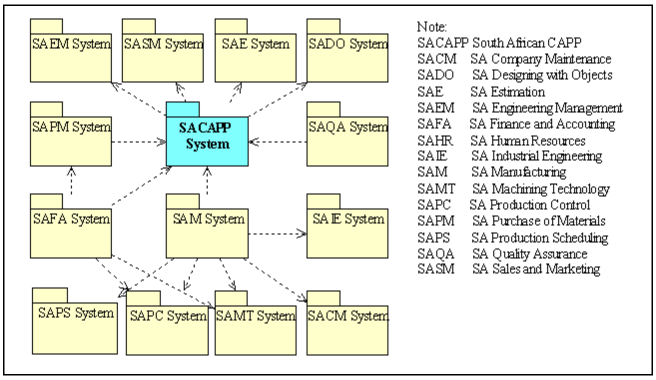
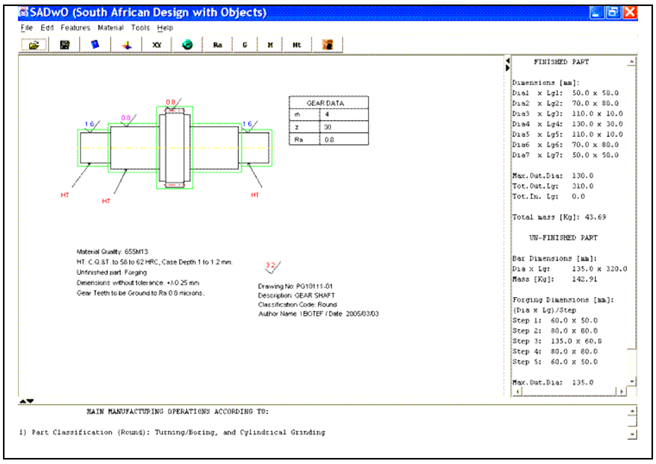


Figure 9. SACAPP, a system of systems

At high level, SACAPP is considered in many respects, an extension of the CAD system, but in the same time, SACAPP is also considered an extension of the Management, Sales, and Quotation systems, an approach in line with the real activities in an industrial company (see Figure 9).

Based on this architecture, methods, and approaches, a prototype was developed in order to prove the concepts (see Figure 10 and Figure 11).



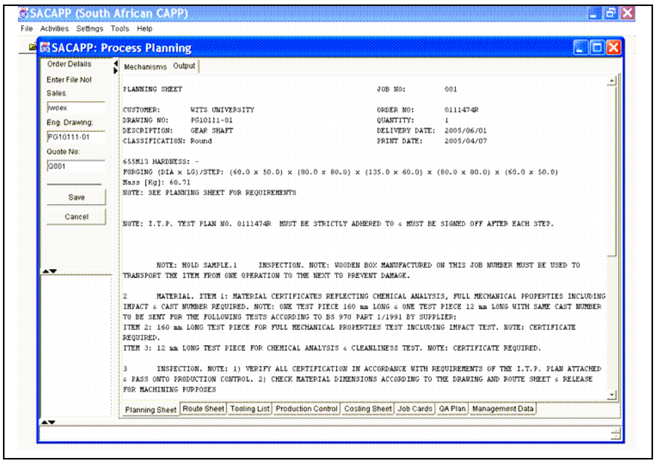
Material Quality: 655M13
HT: C.Q.&T. to 58 to 62 HRC, Case Depth 1 to 1.2 mm.
Unfinished part: Forging
Dimensions without tolerance: +/-0.25 mm
Gear Teeth to be Ground to Ra 0.8 microns.

Drawing No: PG10111-01
Description: GEAR SHAFT
Classification Code: Round
Author Name: IBOTEF / Date: 2005/03/03

```
     FINISHED PART

Dimensions [mm]:
Dia1  x Lg1:  50.0 x 50.0
Dia2  x Lg2:  70.0 x 80.0
Dia3  x Lg3:  110.0 x 10.0
Dia4  x Lg4:  130.0 x 30.0
Dia5  x Lg5:  110.0 x 10.0
Dia6  x Lg6:  70.0 x 80.0
Dia7  x Lg7:  50.0 x 50.0

Max.Out.Dia:  130.0
Tot.Out.Lg:   310.0
Tot.In. Lg:   0.0

Total mass [Kg]: 43.69

    UN-FINISHED PART

Bar Dimensions [mm]:
Dia x Lg:     135.0 x 320.0
Mass [Kg]:    142.91

Forging Dimensions [mm]:
(Dia x Lg)/Step
Step 1:  60.0 x 50.0
Step 2:  80.0 x 80.0
Step 3:  135.0 x 60.0
Step 4:  80.0 x 80.0
Step 5:  60.0 x 50.0

Max.Out.Dia:  135.0
```

```
          MAIN MANUFACTURING OPERATIONS ACCORDING TO:

1) Part Classification (Round): Turning/Boring, and Cylindrical Grinding
```

Figure 10. SADwO screen shot



Enter File No!
Sales: iwoex
Eng. Drawing: PG10111-01
Quote No: Q001

```
PLANNING SHEET                                          JOB NO:        001

CUSTOMER:       WITS UNIVERSITY                         ORDER NO:      0111474R
DRAWING NO:     PG10111-01                              QUANTITY:      1
DESCRIPTION:    GEAR SHAFT                              DELIVERY DATE: 2005/06/01
CLASSIFICATION: Round                                   PRINT DATE:    2005/04/07

655M13 HARDNESS: -
FORGING (DIA x LG)/STEP: (60.0 x 50.0) x (80.0 x 80.0) x (135.0 x 60.0) x (80.0 x 80.0) x (60.0 x 50.0)
Mass [Kg]: 60.71
NOTE: SEE PLANNING SHEET FOR REQUIREMENTS


NOTE: I.T.P. TEST PLAN NO. 0111474R  MUST BE STRICTLY ADHERED TO & MUST BE SIGNED OFF AFTER EACH STEP.



       NOTE: HOLD SAMPLE.1     INSPECTION. NOTE: WOODEN BOX MANUFACTURED ON THIS JOB NUMBER MUST BE USED TO
TRANSPORT THE ITEM FROM ONE OPERATION TO THE NEXT TO PREVENT DAMAGE.

2      MATERIAL. ITEM 1: MATERIAL CERTIFICATES REFLECTING CHEMICAL ANALYSIS, FULL MECHANICAL PROPERTIES INCLUDING
IMPACT & CAST NUMBER REQUIRED. NOTE: ONE TEST PIECE 160 mm LONG & ONE TEST PIECE 12 mm LONG WITH SAME CAST NUMBER
TO BE SENT FOR THE FOLLOWING TESTS ACCORDING TO BS 970 PART 1/1991 BY SUPPLIER:
ITEM 2: 160 mm LONG TEST PIECE FOR FULL MECHANICAL PROPERTIES TEST INCLUDING IMPACT TEST. NOTE: CERTIFICATE
REQUIRED.
ITEM 3: 12 mm LONG TEST PIECE FOR CHEMICAL ANALYSIS & CLEANLINESS TEST. NOTE: CERTIFICATE REQUIRED.

3      INSPECTION. NOTE: 1) VERIFY ALL CERTIFICATION IN ACCORDANCE WITH REQUIREMENTS OF THE I.T.P. PLAN ATTACHED
& PASS ONTO PRODUCTION CONTROL. 2) CHECK MATERIAL DIMENSIONS ACCORDING TO THE DRAWING AND ROUTE SHEET & RELEASE
FOR MACHINING PURPOSES
```

Figure 11. SACAPP screen shot

The SACAPP and other collaborative software systems are developed using Rational Rose and JBuilder 7 Enterprise.

4 Conclusion

In this paper we introduced SACAPP's collaborative paradigm, which can be expected, over time, shift toward and expand the notion of IT infrastructure, and consequently become a mechanism for company integration. The architecture offers simplicity, computability, reusability, and improved communication. All these in turn are expected to create the environment that will facilitate new research developments in fields such as process control at high and low CAPP levels, semi-automated man-machine interfaces capable of better supporting the human operator, and promote technology transfer, education, and training.

References:

[1] IWG/IT R&D, High Confidence Software and Systems Research Needs, *Interagency Working Group on Information Technology Research and Development*, White House National Science and Technology Council, 2001.

[2] OMG, Manufacturing Enterprise Systems, *Object Management Group Manufacturing Domain Task Force*, White paper, 1996.

[3] Rozenfeld, H. and Kerry, H. T., Automated process planning for parametric parts, *Int. J. of Production Research*, Vol.37, No.17, 1999, pp. 3981-3993.

[4] Zhang, H. C., Manufacturing Process Planning, chapter 29 in Dorf, C. R. and Kusiak, A., *Handbook of Design, Manufacturing and Automation*, Wiley-Interscience Press, 1994.

[5] ElMaraghy, H. A., Evolution and future perspectives of CAPP, *Annals of the CIRP*, Vol.42, No.2, 1993, pp. 739-751.

[6] Rodd, M. G, Verbruggen, H. B, and Krijgsman, A. J., Artificial intelligence in real-time control, *Engineering Applications of Artificial Intelligence*, Vol.5, No.5, 1992, pp. 385-399.

[7] Prasad, B., Converting computer-integrated manufacturing into an intelligent information system by combining CIM with concurrent engineering and knowledge management, *Industrial Management and Data Systems Journal*, Vol.100, No.7, 2000, pp. 301-316.

[8] Ming, X. G., Mak K. L., and Yan J. Q., A hybrid intelligent inference model for computer aided process planning, *Integrated Manufacturing Systems Journal*, Vol.10, No.6, 1999, pp. 343-353.

[9] Jain, P. K., Automatic cut planning in an operative process planning system, *Proc Instn Mech Engrs Part B*, Vol.212, 1998, pp. 129-140.

[10] Law, H. W. and Tam, H. Y., Object-oriented analysis and design of computer aided process planning systems, *Int. J. of Computer Integrated Manufacturing*, Vol.13, No.1, 2000, pp. 40-49.

[11] AAAI, Artificial intelligence and manufacturing, a research planning report, *American Association for Artificial Intelligence, Special Interest Group for Manufacturing*, Sandia National Laboratories, AAAI Press, 1997.

[12] McMahon, C. A., Cox D. R., Williams J. H. S., and Scott J. A., Representation and reasoning in computer aided process planning, *Proc Instn Mech Engrs Part B*, Vol.211, 1997, pp. 473-485.

[13] Kryssanov, V., Kleshchev A. S., Fukuda Y., and Konishi K., Building a logical model in the machining domain for CAPP expert systems, Int. *J. of Computer Integrated Manufacturing*, Vol.36, No.4, 1998, pp. 1075-1089.

[14] Hugh, J., *A Boolean algebra approach to high-level process planning*, Ph.D. thesis, University of Western Ontario, Canada, 1994.

[15] Groover, M. P., *Automation, Production Systems and Computer-Integrated Manufacturing*, Second Edition, Prentice Hall, 2001.

[16] Turner, B., Workforce issues of 2020, *American National Research Council's Board on Manufacturing and Engineering Design, Visionary manufacturing Challenges for 2020 Report*, Washington D.C., National Academy Press, 1998.

[17] Shin, W., 1998, Reengineering through fractal structures, *American National Research Council's Board on Manufacturing and Engineering Design, Visionary manufacturing Challenges for 2020 Report*, Washington D.C., National Academy Press.

[18] Jacobson, I., Booch, G., and Rumbaugh, J., *The Unified Software Development Process*, Addison-Wesley, 1999.

[19] Kazman, R. and Bass, L., Making architecture reviews work in the real world, *IEEE Software*, January/February, 2002, pp. 67-73.

[20] Vliet, van H., *Software Engineering - Principles and Practice*, John Wiley & Sons, Ltd., 2000.

[21] Budd, T., *Classic Data Structure in Java*, Addison Wesley Longman Inc., 2001.

[22] Wildberger M., AI and Simulation, *Simulation Journal*, Vol.74, No.5, 2000, pp. 109-110.

[23] Morley, R., Complexity theory and new ways to think about manufacturing, *American National Research Council's Board on Manufacturing and Engineering Design Report*, Washington D.C., National Academy Press, 1998.