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Collaborative process planning and manufacturing in product lifecycle management

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Abstract

Companies are moving towards quickly providing better customer-centric products and services improve market share and market size with continuously growing revenue. As such, the effective collaboration among customers, developers, suppliers, and manufacturers throughout the entire product lifecycle is becoming much more important for the most advanced competitiveness. To address this need, a framework for product lifecycle collaboration is proposed in this study. The details of these collaboration models throughout the entire product lifecycle are depicted. As one of the key elements in product lifecycle collaboration, technology to support collaborative product manufacturing is proposed, developed and implemented in this study. It is hoped that the developed technology for collaborative product manufacturing will lay a frontier basis for further research and development in product lifecycle management.

Keywords: Product lifecycle management; Collaborative product manufacturing; Collaborative engineering; Computer aided process planning; Computer aided manufacturing

1. Introduction

Manufacturers are facing increasing challenges of better product quality with tighter delivery requirements for customers, more profitability shareholders. Global competition is increasing with pressure on prices, smaller orders, shorter life cycles, more suppliers, more governmental regulations, and increasing material and energy costs. These new business drivers make manufacturers pursue more competitive business model, such as collaborative manufacturing, to closely collaborate with their customers, suppliers, manufacturers and partners for the most advanced competitiveness by leveraging core competencies throughout the entire product lifecycle [1].

In collaborative manufacturing, product lifecycle management (PLM) has recently been recognized as a new strategic business model to support collaborative creation, management, dissemination, and use of product assets, including data, information, knowledge, etc., across extended enterprise from concept to end of life—integrating people, processes, and technology. PLM systems support the management of a portfolio of products, processes and services from initial concept, through design, engineering, launch, production and use to final disposal. They coordinate and collaborate products, project and process information throughout the entire product value chain among various players, internal and external to enterprise. They also support a product-centric business solution that unifies product lifecycle by enabling online sharing of product knowledge and business applications [2–4].

As such, PLM enables manufacturing organizations to obtain competitive advantages by creating better products in less time, at lower cost, and with fewer defects than ever before. In summary, PLM not only provides process management throughout the entire product lifecycle, but also enables effective collaboration among networked participants in product value chain, which distinguishes it from other

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enterprise application systems, such as enterprise resource planning (ERP), supply chain management (SCM), customer relationship management (CRM), etc.

To tackle the collaboration challenges in PLM, this study begins with recent status review and gap analysis in Section 2. Based on the analyzed gap, a model for product lifecycle collaboration is proposed in Section 3. As one of the most important parts of in product lifecycle collaboration, the key technology to enable collaborative product manufacturing, which is collaborative process planning and manufacturing, is developed in Section 4. The detailed system design of such a collaborative process planning and manufacturing is developed in Section 5. A demonstration is given in Section 6. Finally, conclusions are made and future perspectives are given.

2. State-of-the-art review

Modern enterprises are facing ever increasing challenges of shorter product lifecycles, increased outsourcing, mass customization demands, more complex products, geographically dispersed design teams, inventories subject to rapid depreciation, and rapid fulfillment needs.

To effectively tackle these challenges in modern collaborative business environment, new industrial capabilities are required in order to obtain competitive advantages in today's Internet economy:

(1) Geographically scattered design teams and supply chain partners need to collaboratively design products on a virtual basis.
(2) Static designs need to be replaced by mass customization, often using predefined modules or building blocks to rapidly configure new product platforms that can be flexibly managed through their lifecycle.
(3) To exchange and control product information and to perform real-time program/project management.
(4) A system needs to emerge as the dominant technology for managing inter-enterprise data, information and knowledge, and providing design teams with a virtual design space.

To meet these addressed requirements, new technology solutions are imperatively required:

(1) To provide an information continuum to deliver pervasive, real-time analytics, querying and reporting throughout the entire product lifecycle.
(2) To provide a collaborative environment bringing together multiple roles, constituents and stake-holders in threaded discussions beyond four walls of enterprise.
(3) To enable interactive viewing and commentary upon product lifecycle through multiple devices, channels and systems involved with product lifecycle.
(4) To be an open but integrated solution supporting key enterprise value disciplines of product leadership, customer intimacy, and operational excellence.

Such a new system will provide customers, developers, manufacturers, suppliers and partners with following capabilities:

(1) Product lifecycle collaboration across virtual enterprises.
(2) Effective management of product lifecycle activities.
(3) Convenient integration with other enterprise systems.

To satisfy continuously emerging new business challenges, in several past decades, both academic and industrial researchers have engaged tremendous efforts in research and development of industrial information technologies to pursue the most competitive business advantages in product lifecycle.

A recent academic state-of-the-art review or the research effort related to PLM reveals that the academic pioneer in product lifecycle research is the product life cycle modeling group at University of Tokyo [5], focusing on the topics of life cycle engineering, life cycle design based on simulation, life cycle planning, life cycle optimization, reuse and rapid life cycle, eco-design, service-quality, etc. The other effort includes center for design research at Stanford University [6], center for innovation for product development at Massachusetts Institute of Technology [7], web based design, process planning and manufacturing system at University of California at Berkeley [8], systems realization laboratory at Georgia Institute of Technology [9], design process and knowledge management at engineering design center of Cambridge University, computer aided concept design at engineering design center of Lancaster University, FIPER project funded by National Institute of Standard and Technology in USA [10], iViP project funded by Fraunhofer in Germany [11]. Such research effort focused on product design and development activities by using modern computing and Internet technologies to facilitate design collaboration and potential innovation. These reported achievement forms the strong basis for further research and development in product lifecycle management. However, little effort has been documented on product lifecycle technology, as what Tokyo University reported, and the result obtained is still far from satisfactory.

The recent industrial status of PLM solutions from world leading vendors shows that UGS PLM solution provides the capability of collaboration platform, collaborative project management and so on based on Teamcenter infrastructure [12]. PTC provides the solution extended from traditional product data management (PDM) to link with supplier and project management [13]. IBM supports extended PDM solution for both multi-national companies (MNCs) via Enovia and small and medium-sized enterprises (SMEs) via Smarteam [14]. MatrixOne supports solutions of collaborative application, lifecycle application, and modeling studio [15]. Agile Soft [16] provides solutions of product definition, product collaboration, product sourcing, etc. These solutions from different vendors, particularly the PDM solutions, have been widely applied in manufacturing industry and created beneficial impact to enterprises.

However, current product design and development in most companies still encounter a lot of difficulties, such as

- Shifting design from a departmental and sequential process to a cross-company and concurrent activity has been discussed for several years.
- Using traditional product data management systems and exchanging engineering data with suppliers has proved difficult, slow, and geographically limited.
- Flawed coordination between teams, systems and data incompatibility, and complex approval processes are common.
- Too often result is late product introductions, distraction of high-value staff, quality problems, or supply chain complications.

This is because that, traditional application systems, e.g., computer aided design (CAD)/computer aided manufacturing (CAM) [17], computer aided process planning (CAPP) [18], helped to make design process more efficient, but they were usually separate from a manufacturing company's mainstream operations. Design engineers and possibly manufacturing engineers could access these systems, but others who may have been able to add value to the design had no systematic process by which to influence or even comment on product design. By the time these other participators provided their input, changes were either very costly to implement or were not made at all, resulting in high costs or – even worse – an inefficient product design that did not meet customer needs. Even though the modern manufacturing application systems, such as, product data management (PDM), supply chain management (SCM), enterprise resource management (ERP), manufacturing execution system (MES), customer relationship management (CRM), demand chain management (DCM), and so on, have been developed to overcome certain aspects of the above difficulties, they still cannot adequately address the need for collaborative capabilities throughout the entire product lifecycle because they focus on special activities in an enterprise and are not adequately designed to meet new collaborative business requirements [19–21].

3. Product lifecycle collaboration

In order to tackle new challenges in modern collaborative business environment, there needs a new collaborative business solution to enable:

(1) Changing the way the world brings products to market by leveraging the power of product collaboration across global value chains of trusted partners, employees, suppliers, and customers.
(2) Delivering product collaboration solutions for successful value chains that are specially designed to:
   - speed product development,
   - manage programs effectively,
   - enable strategic sourcing.
(3) Early strategic supplier, customer and partner involvement in collaborative product and supply chain processes:
   - reduces development costs,
   - increase product innovation,
   - dramatically speeds time to market,
   - results in a strategic impact on revenue.

As such, a new technology solution, called, "product lifecycle collaboration", is required (Fig. 1). Functions of to enable product lifecycle collaboration include, but not limited to, product portfolio management (PPM), collaborative product customization (CPC), collaborative product development (CPD), collaborative product manufacturing (CPM), collaborative component supply (CCS), and extended product service (EPS). In particular, the collaboration protocol, which

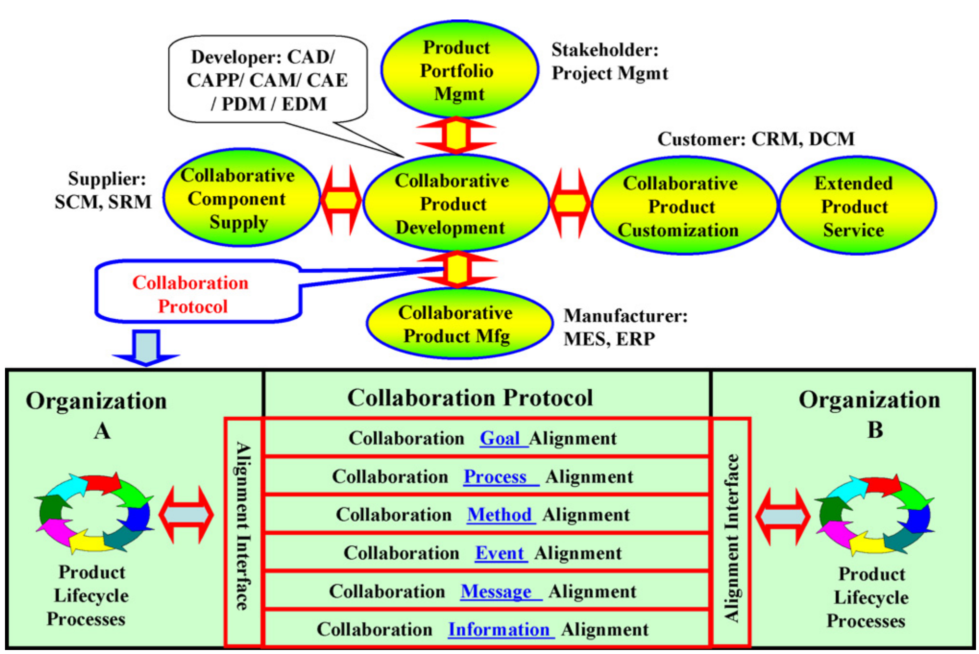


Fig. 1. A schematic view of product lifecycle collaboration.

provides different companies with general regulation to facilitate real time collaboration throughout the entire lifecycle, is imperatively required. This collaboration protocol includes different layers of collaboration alignment, such as goal, process, method, message, and information.

It is expected that the development of collaborative solutions for product lifecycle collaboration will provide enterprises with technical advantages as follows:

(1) Providing effective collaboration for product lifecycle users.
(2) Breaking down barriers to innovation.
(3) Servicing customer much better.

4. Process planning and manufacturing collaboration

One of the most important collaborative activities in collaborative product manufacturing in product lifecycle management is collaboration between process planning and manufacturing, where computer aided process planning (CAPP) and computer aided manufacturing (CAM) represent the roles. Following sub-sessions will depict the details of the collaborative process planning and manufacturing.

4.1. Integrated process planning system

An integrated manufacturing process planning framework includes process planning activities and integration with other application systems (Fig. 2). In tooling production, these application systems are normally CAD, CAM, ERP/CPS (enterprise resource planning/ capacity planning and scheduling), and MRM (manufacturing resource management) systems. Operations selection function selects manufacturing operations according to part and feature information, material, tolerance, etc. Routing planning function generates and sequences processes, selects machines for each process. Setup planning generates and sequences setups, selects fixtures for each setup, sequences operations within each setup. Operations planning function selects cutting tools and cutting parameters, etc. Manufacturing resource management module provides the necessary capabilities to define the required resources and the capabilities to enable the implementation of the operations selection, route planning, setup planning and operations planning functions. Operations selection function normally integrates with the CAD system to retrieve the defined manufacturing features and select the corresponding manufacturing operations. Route planning, setup planning, and operations planning functions usually interact with the ERP/CPS systems by providing the necessary manufacturing process routings, setups, and operations for project, production and shop-floor scheduling. Setup planning and operation planning functions communicate with the CAM system by providing setups, and operation information, which includes cutting tools and cutting parameters to generate the NC codes.

4.2. Collaboration between CAPP and CAM

The collaborative actions between process planning and NC programming includes (Fig. 3).

- Exchange of message regarding process routes and machines between function of process route sequence and machine selection in CAPP and function of identifying manufacturing process and machines in CAM.

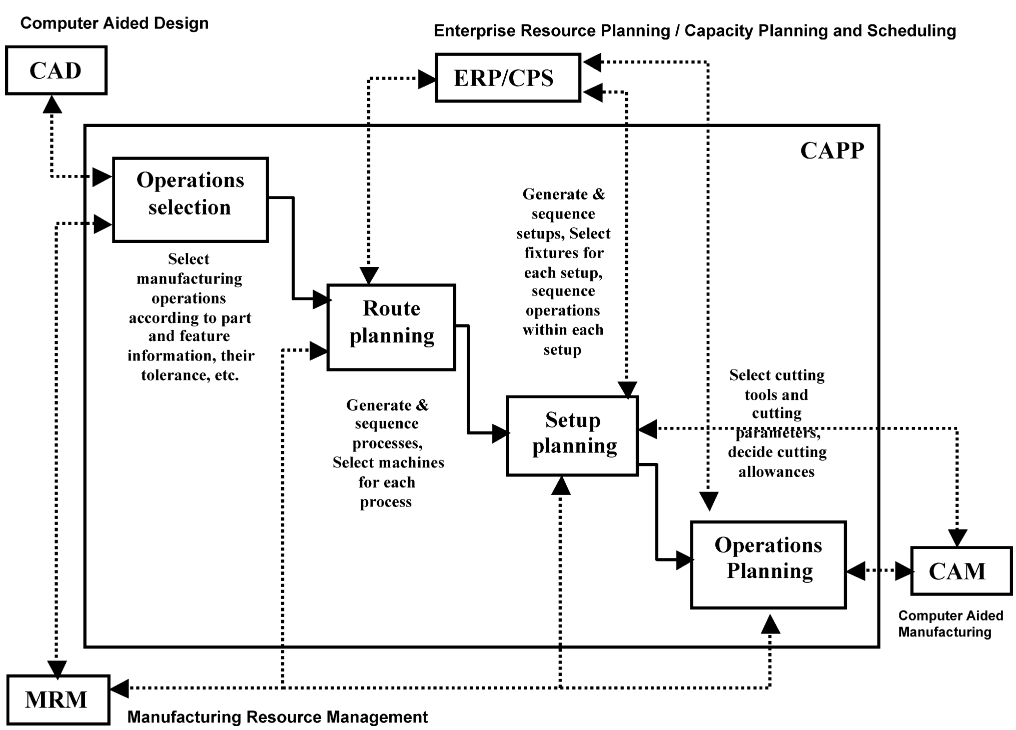


Fig. 2. Framework of an integrated CAPP system.

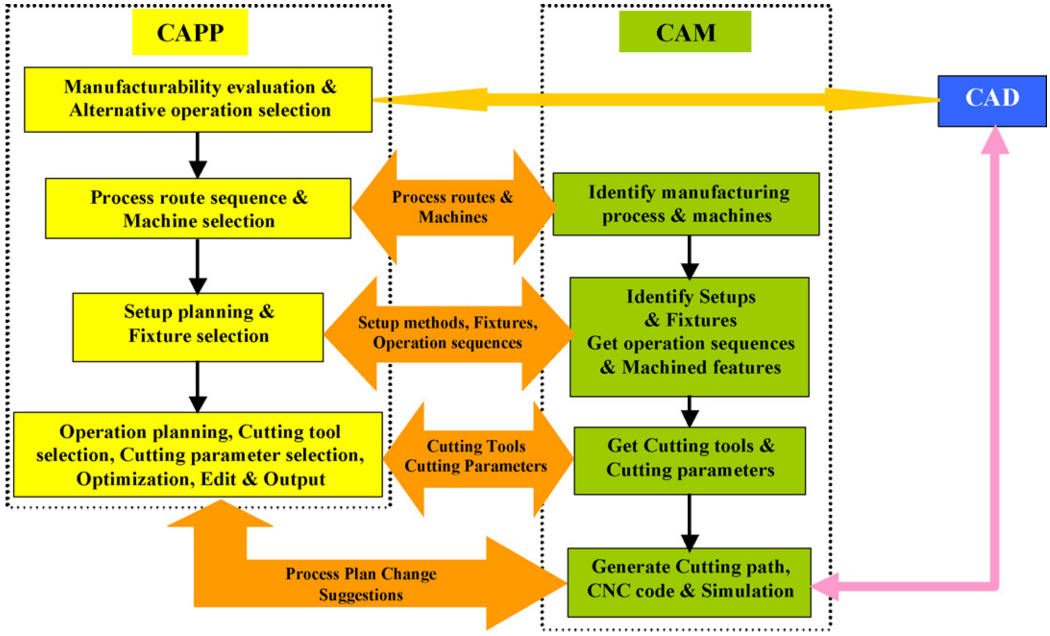


Fig. 3. Conceptual view of CAPP/CAM collaboration.

- Exchange of message regarding setup methods, fixtures and operations sequences between function of setup planning and fixture selection in CAPP and function of identifying setups, fixtures, getting operation sequences and machined features in CAM.
- Exchange of cutting tools and cutting parameters between function of operation planning, cutting tool selection, cutting parameter selection, optimization, edit and output in CAPP and function of getting cutting tools and cutting parameters in CAM.
- Exchange of process plan change suggestions between function of operation planning, cutting tool selection, cutting parameter selection, optimization, edit and output in CAPP and function of generating cutting path, CNC code and simulation in CAM.

Details of the events, sender, receiver, triggered functions, parameters and associated messages are designed and depicted in Table 1.

4.3. Technical advantages

By developing the above new technologies, following potential end user benefits are expected:

Table 1
Relationships among events, functions and messages

	Events	Sender/receiver	Triggered functions	Parameters	Associated messages
1	Part not planned	CAM/CAPP	Operation planning and sequencing	Part ID	'Operation of part X is not planned'
2	Operation planning finished	CAPP/CAM	Update project/product/part information	Part ID	'Operation planning of part X is finished'
3	Cutting tools not selected	CAM/CAPP	Cutting tools selection	Operation ID	'Cutting tools of operation X of part Y are not selected'
4	Cutting parameters not selected	CAM/CAPP	Cutting parameters selection	Operation ID	'Cutting parameters of operation X of part Y are not selected'
5	Cutting tools selection finished	CAPP/CAM	Update cutting tools values	Operation ID	'Cutting tools selection of operation X of part Y is finished'
6	Cutting parameters selection finished	CAPP/CAM	Update cutting parameters values	Operation ID	'Cutting parameters selection of operation X of part Y is finished'
7	Request for a discussion with CAPP	CAM/CAPP	Discuss on modification	Operation ID	'Request for a discussion on cutting tools/parameters modification of operation X of part Y'
8	Cutting tools modification finished	CAPP/CAM	Update cutting tools values	Operation ID	'Cutting tools modification of operation X of part Y is finished'
9	Cutting parameters modification finished	CAPP/CAM	Update cutting parameters values	Operation ID	'Cutting parameters modification of operation X of part Y is finished'

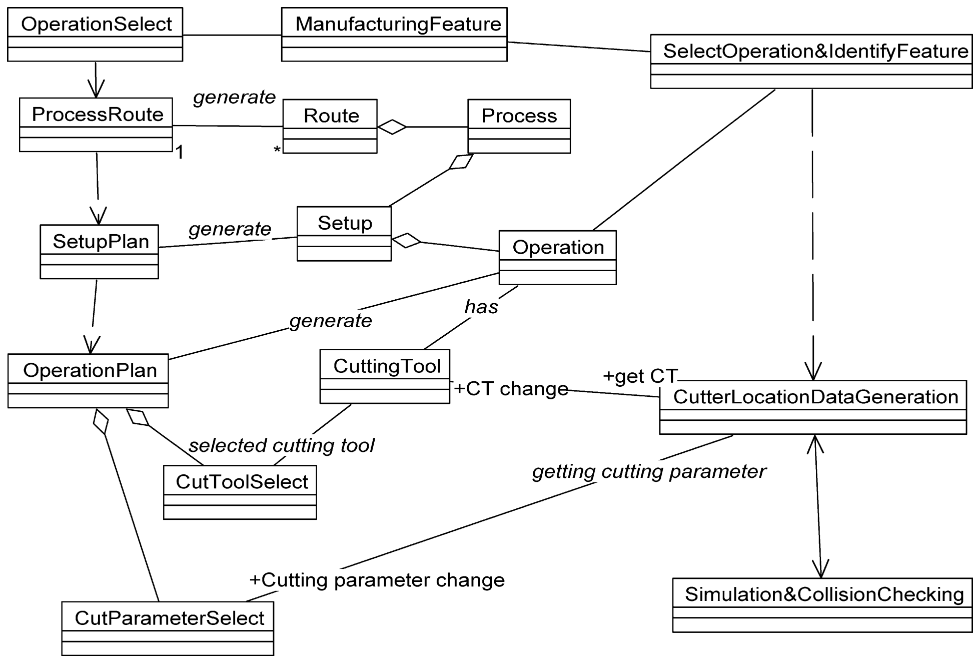


Fig. 4. Information integration of CAPP/CAM in UML.

- Shorter production leader time due to effective collaboration process planner and NC programmer.
- Quick time-to-volume with effective collaborative manufacturing capability.
- Lower product cost with efficient collaborative process planning and NC programming.

5. Collaborative system design

The system design of collaborative process planning and manufacturing includes the information integration, functional collaboration and user interface for collaboration, and the details are depicted as follows.

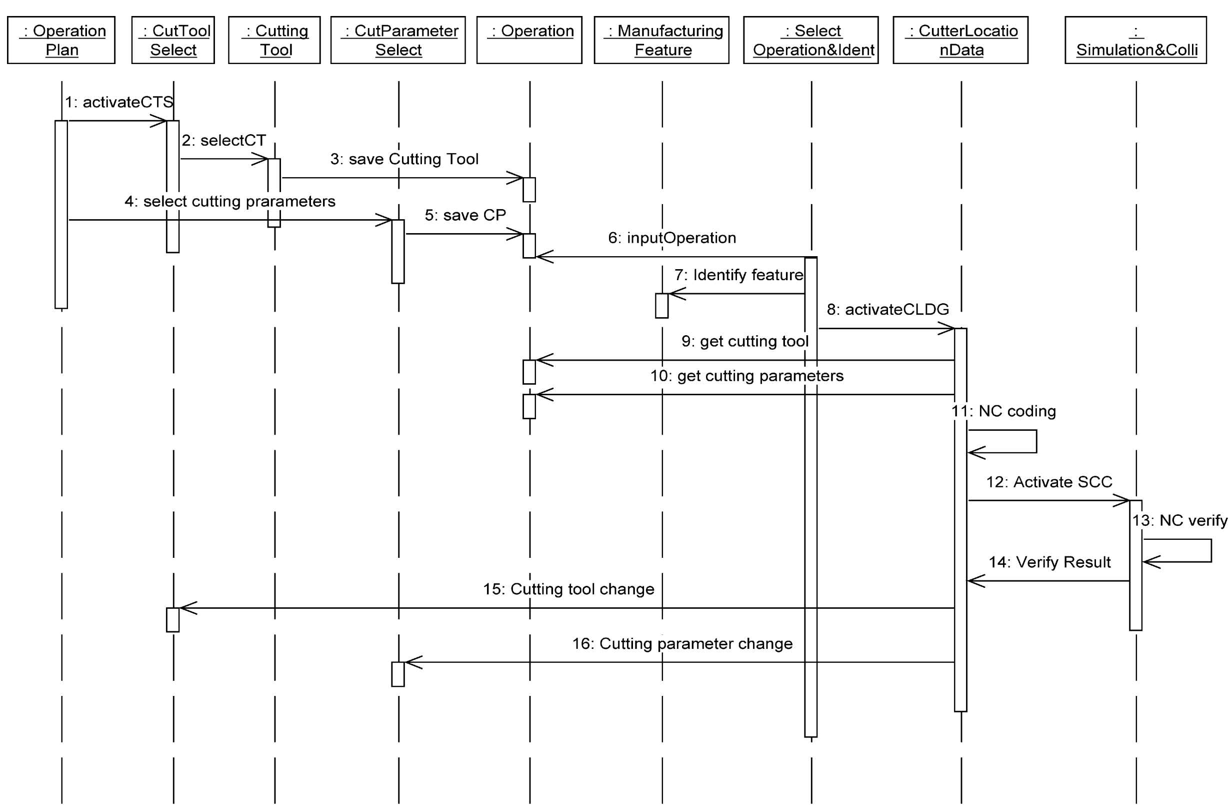


Fig. 5. Functional collaboration of CAPP/CAM in UML.

5.1. Information integration

The information integration represents the exchange of the required data between CAPP sub-system and CAM sub-system (Fig. 4). It consists of

(1) Selection of operation and identifying corresponding features, which links to the data entities of manufacturing feature and operation.
(2) Generation of cutter location data, which links to cutting tool for the exchange of cutting tool change data.
(3) Generation of cutter location data, which links to cutting parameter selection for the exchange of cutting parameter change data.

5.2. Functional collaboration

The functional collaboration depicts the interactive processes between CAPP sub-system and CAM sub-system. As depicted in Fig. 5, it includes the processes to activate cutting tool selection, select cutting tool, save cutting tool, select cutting parameters, save cutting

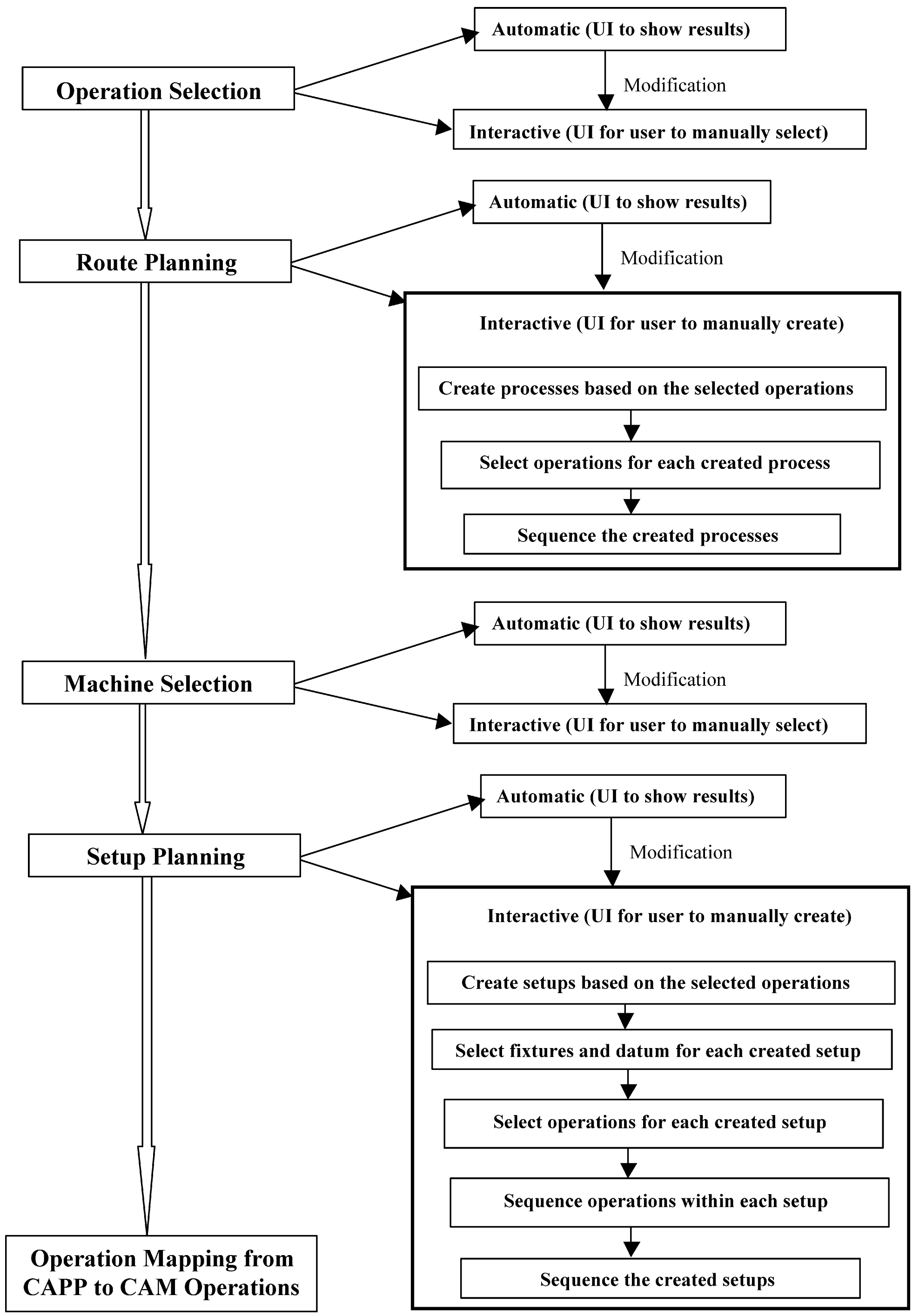


Fig. 6. User interface flow of CAPP for collaborative integration.

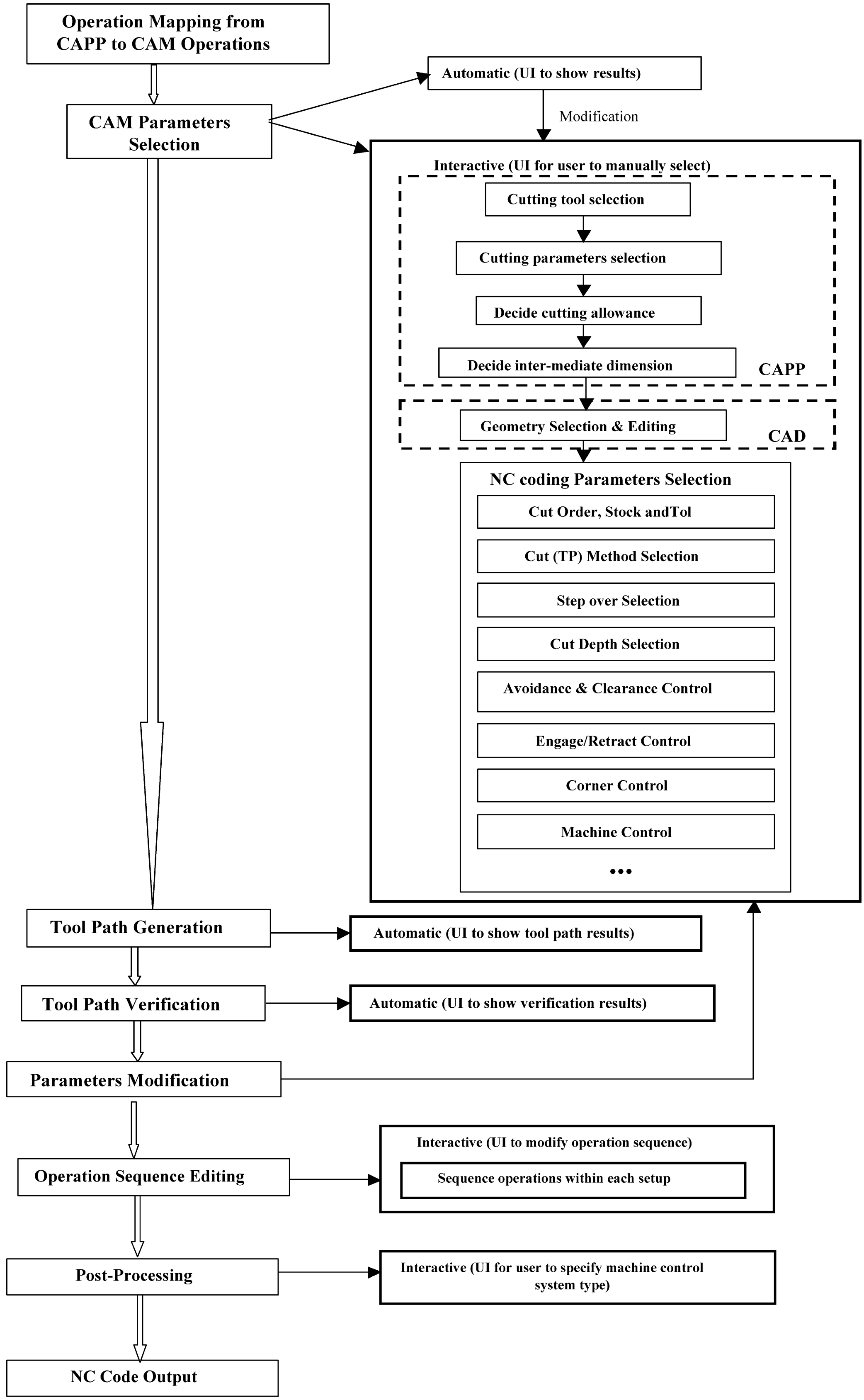
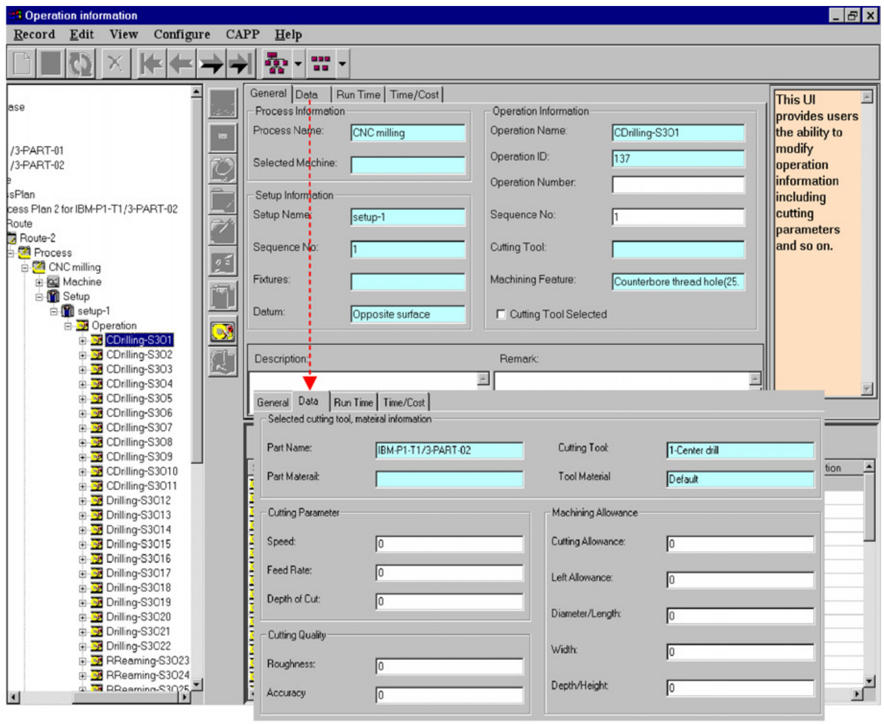


Fig. 7. User interface flow of CAM for collaborative integration.

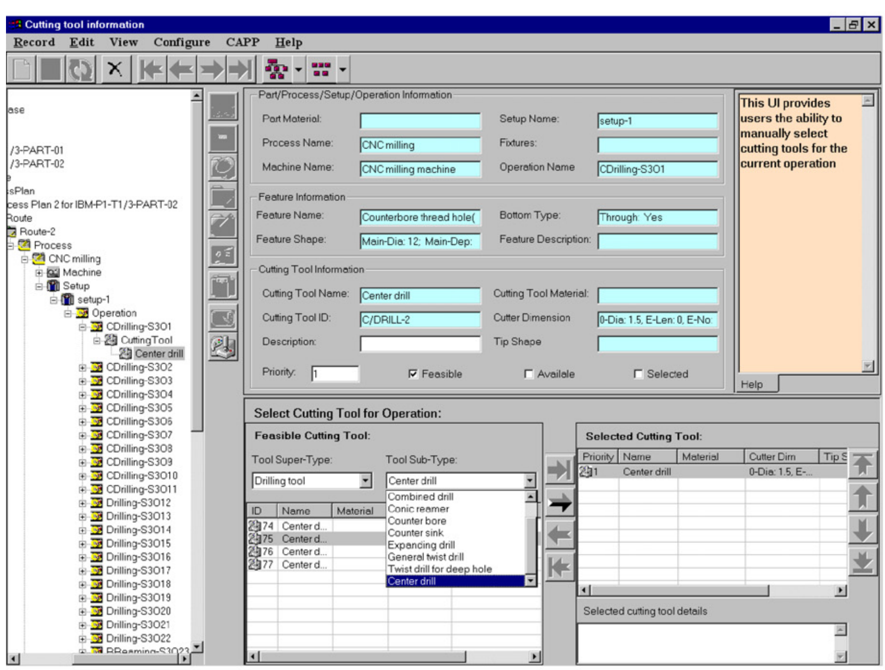
parameters, input operation, identify feature, activate cutter location data generation, get cutting tool, get cutting parameters, generate NC code, activate simulation and collision checking, verify NC code, verify results, request for cutting tool change and cutting parameter change, etc.

5.3. User interface for collaborative integration

The main steps of user interfaces for collaborative integration includes actions (Fig. 6) from CAPP, which are operation selection, route planning, machine selection, setup planning, operation mapping from CAPP to CAM operations,



(a) Specify cutting parameters



(b) Select cutting tools

Fig. 8. User interface for selecting cutting tools and parameters.

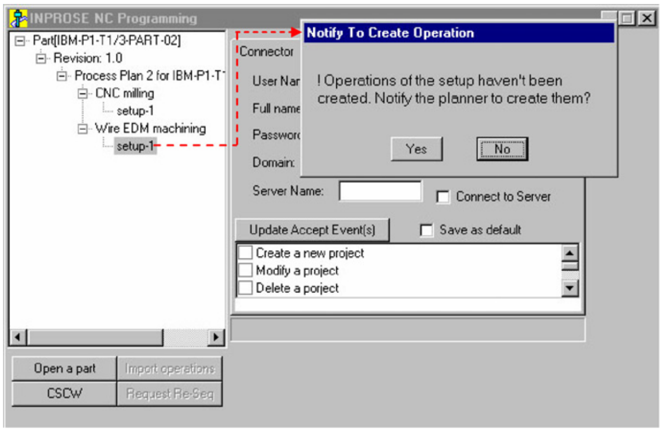


Fig. 9. User interface to notify for generating operations.

and actions (Fig. 7) from CAM, which are CAM parameter selection, tool path generation, tool path verification, parameters modification, operation sequence editing, post-processing and NC code output.

6. System implementation

6.1. Demonstration of collaborative integration

Once the features are created, the process planner can work on the part to create process plans, routes, processes, setups and operations. The collaboration between process planning starts with the selection of cutting tools and cutting parameters (Fig. 8).

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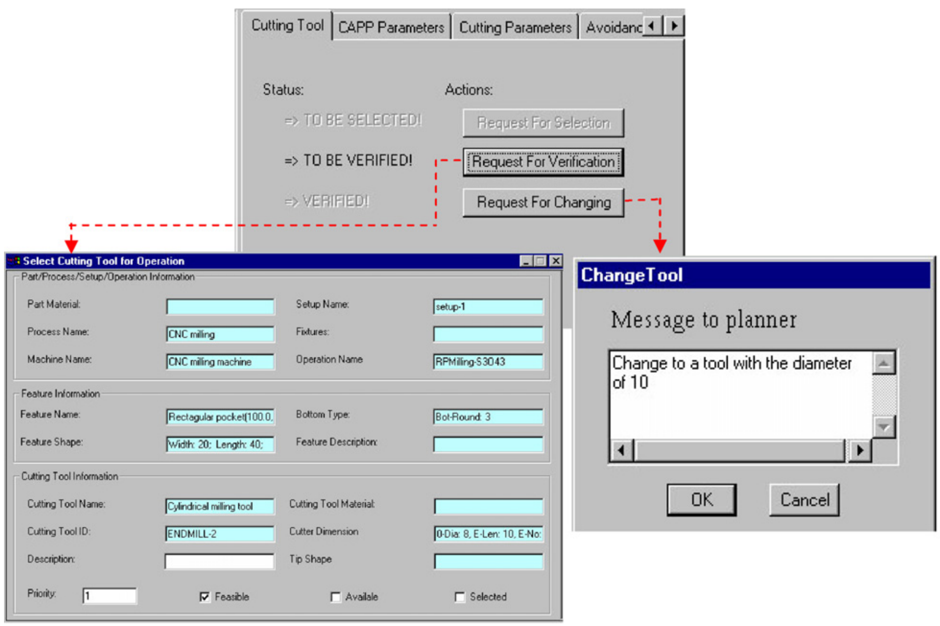
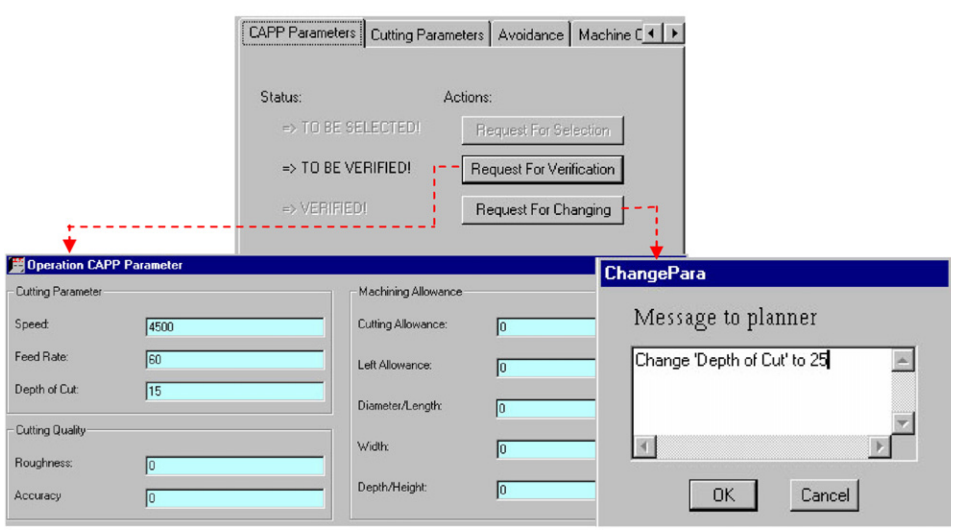


(a) Verify cutting tool



(b) Verify cutting parameters

Fig. 10. User interface for verifying cutting tools and parameters.

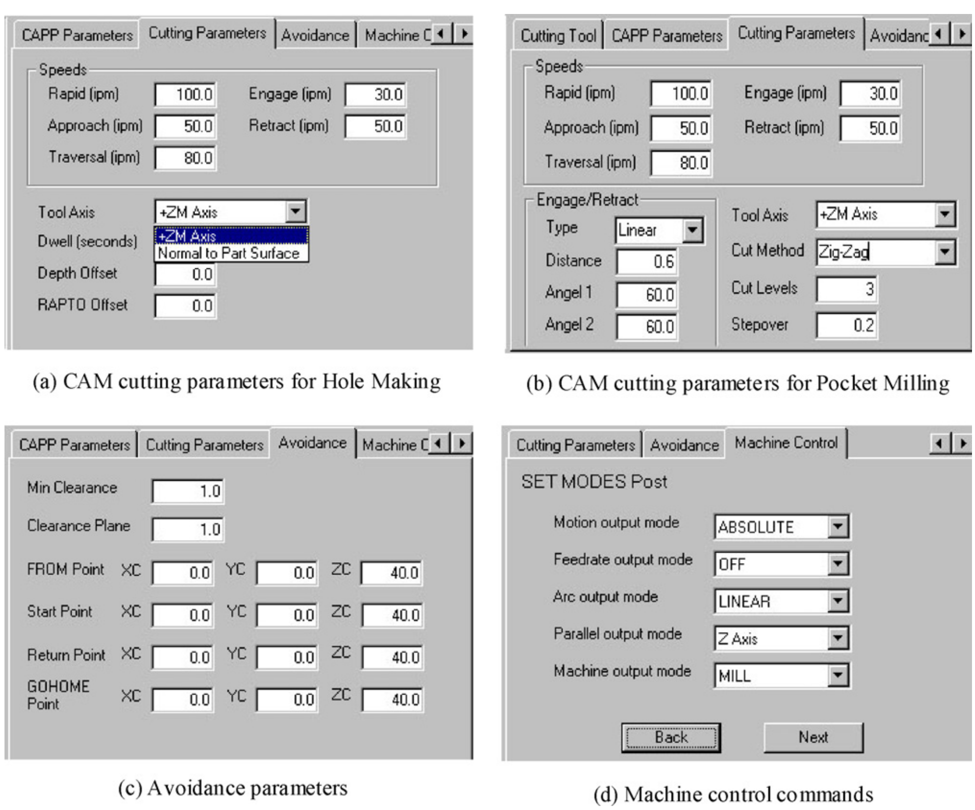
NC programmer can work with the process planner collaboratively. The details of the collaborative activities between process planning and NC programming are to

(1) Import operation. To import the CAPP operations and map them into CAM operations, browse the tree view in the NC programming main window, click the setup in which the operations are going to be imported. If the CAPP operations have been generated by the process planner, a button 'Import operations' will be enabled, and the NC programmer can import the operations by clicking the button. If the operations haven't been generated by the process planner, the button will be disabled and a message box will show up to ask the NC programmer whether to inform the process planner to generate the operations under the setup (Fig. 9).
(2) Verify cutting tool and parameters. The NC programmer can check if cutting tool and parameters have been selected for the operation. If they haven't been selected, the NC programmer can notify the process planner to select them. If they are selected, the NC programmer can verify them by clicking 'Request for Verification' button or request the process planner to change them by clicking 'Request for Changing' button and sending a message to the process planner (Fig. 10). The cutting tool and parameters will be verified when Tool Path generation. If any problem is found, the NC programmer can come back to request changes to the cutting tool and parameters.
(3) Define CAM parameters. The NC programmer needs to define other CAM parameters (Fig. 11), e.g., CAM cutting parameters, Avoidance parameters, Machine control commands, etc. After that, the too path is generated and verified.
(4) Modify operation sequence. If operation sequence is not satisfied due to some reason, the NC programmer can request the process planner to adjust the sequence by sending a message. The process planner adjusts the sequence after receiving the message. An event is then automatically sent from the CAPP module to the CAM module to notify that the sequence has been changed, and the CAM module automatically adjusts the sequence accordingly and update the operation tree view (Fig. 12).
(5) Post-processing. Finally, the NC programmer post-processes the generated tool path to generate NC codes. The post-processing function is utilizing the unigraphics post-processing function. Due to limited space, the post-processing is not depicted here.

6.2. Industrial benefits

The demonstrated system with collaborative process planning and manufacturing technologies developed shows the potential industrial benefits as follows:

- Reduced rework in cutting tool and cutting parameter selection.
- Effective and efficient generation of NC programming for production.
- Optimized operational sequence with NC program verification.



(a) CAM cutting parameters for Hole Making
(b) CAM cutting parameters for Pocket Milling
(c) Avoidance parameters
(d) Machine control commands

Fig. 11. User interface for defining CAM parameters.

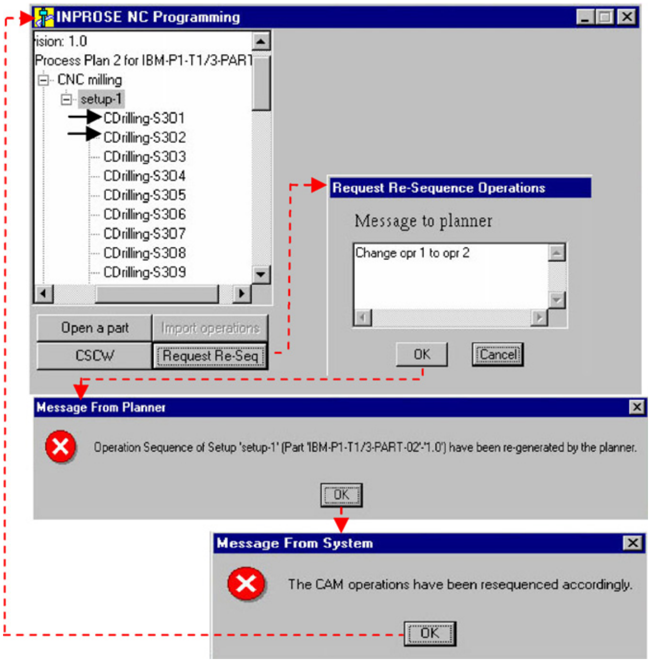


Fig. 12. User interface for collaborative operation re-sequence.

7. Conclusion and future perspectives

To respond to new business requirements of effective collaboration throughout the entire product lifecycle to leverage core competencies, a framework of product lifecycle collaboration has been proposed in this study. The detailed technology, namely, collaborative process planning and manufacturing, to support the collaborative product manufacturing in product lifecycle collaboration, has been developed. The implementation of such a collaborative process planning and manufacturing technology shows the efficiency and effectiveness for collaborative product manufacturing, which in turn lays the frontier foundation for the future development of collaborative in the entire product lifecycle.

Future research will focus on the development of collaboration protocols in throughout the entire product lifecycle, including semantic and mathematical models, and heuristics, business rules, optimization algorithms to improve the performance of such dynamic collaboration among business value chain.

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