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Research on Intelligent CAPP System Based on Multi-Agent System

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Abstract—**The factors such as manufacturing technology, manufacturing resource, product architecture and so on, influence on the function of CAPP system greatly. Different CAPP systems need to be developed for different manufacturing enterprises, their function and application range are restricted severely, so the traditional CAPP systems lack for the agility and dynamic adaptability under the different production environment. In order to improve flexibility, expansibility, reusability, dynamic adaptability of CAPP system, the architecture of an intelligent CAPP based on MAS under concurrent engineering environment was put forward in this paper. Work mechanism and conflict elimination mechanism of intelligent CAPP were researched, and the reasons of conflict generation were analyzed, the conflicts which intelligent CAPP generated were resolved by use of rule-based reasoning and case-based reasoning, the investigation achievement was applied in the process of producing shearer. It is shown that the intelligent CAPP based on multi-agent system has good expansibility and reusability, it can adapt to the changes of products and production conditions in the enterprise.**

Keywords-multi-agent system; computer-aided process planning; work mechanism; conflict elimination

I. INTRODUCTION

The function of CAPP system is decided by enterprise's manufacturing technology, manufacturing resource, product architecture, and so on, the different CAPP systems need to be developed for different manufacturing enterprises. In order to improve the universality and reusability of CAPP system, the foreign and native researchers have studied the development method and system architecture of CAPP system from the 1970s. They put forward hybrid CAPP, progressive CAPP and CAPP development platform in [1] and [2], and so on. But these CAPP systems which are applied practically in the manufacturing enterprises are very few. For example, the change of the hybrid decision strategies and the design of knowledge base are very difficult in the hybrid CAPP system. Because of diversity and complexity of parts, it is very complicated to modify and complete the prototype of process plans in the progressive CAPP. The reusability and adaptability of the CAPP system based on component technology were improved greatly, but software component is absent of autonomous ability, adaptive reasoning ability, and own knowledge base, CAPP based on component technology compared with traditional CAPP in the aspect of dynamic optimization decision of process plans, it's adaptability has not obvious improvement. In order to improve dynamic adaptability of CAPP, Reference [3] and [4] presented the integration model between CAPP and production planning and control system. For the above-mentioned reasons, an intelligent CAPP system based on Multi-Agent System (MAS) was investigated to improve the flexibility, expansibility, reusability, dynamic adaptability of CAPP system.

II. THE SYSTEM ARCHITECTURE OF THE INTELLIGENT CAPP SYSTEM BASED ON MULTI-AGENT SYSTEM

MAS represents an application field or a problem which needs many solution entities, the system not only has the advantage of distributed and concurrent problem-solution, but also the ability of multi-Agent cooperation to deal with problems. These characteristics of MAS have been used to solve the distributed and dynamic problems by the foreign and native researchers in the manufacturing domain. The CAPP based on MAS were researched in [5] and [6], and architecture of Agents in CAPP was described. In the intelligent CAPP system based on MAS, CAPP system is divided into several separate Agents with independent functions, and all the Agents are both independent and interaction. Each Agent has own controller, inference engine, knowledge base and problem-solution strategy, but its resource, ability and information were limited, they will complete process planning by the cooperation and coordination.

A. The Division Principle for Intelligent CAPP System

In the intelligent CAPP system, the execution time that a sub-function spends in an Agent mainly consists of two parts. One part is the time for reasoning and problem-solution, and the other is the time for communicating with each other. In the process of function division, on one hand, if the particle size of function is too big, the independence and knowledge module of Agent function will be influenced, so that the reusability and practicability of system will be reduced. On the other hand, if the particle size of function is too small, the communication time among the Agents will be increased, and the work efficiency will be reduced. In the process of design and development of intelligent CAPP system, the principles of the function division for Agent include the following contents:

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(1) The multilevel and mixed Agent system architecture was adopted to ensure the independent function of the lower Agents, and the communication delay is reduced.

(2) Each task should be covered by one Agent.

(3) If there is communication requirement, every Agent should be able to cooperate with other Agent, and synthesize local functions to assure the accomplishment of system function.

(4) Every Agent could be realized logically or physically.

The Agents of the small particle size should be combined easily to form the Agents of the big particle size during work process.

B. The Structure of The Intelligent CAPP System

Under the contemporary integrated manufacturing system, CAPP system should possess good flexibility, expansibility, reusability and dynamic adaptability. In addition, the CAPP system should be integrated with computer-aided design (CAD) and Production Planning and Control (PPC) system to generate process planning which adapts to the actual production status in the job-shop. In order to meet the requirements of contemporary integrated manufacturing system, the structure of intelligent CAPP system based on MAS was put forward and shown in Fig.1. According to the functions, tasks and targets of CAPP system, the Agents of the CAPP were divided.

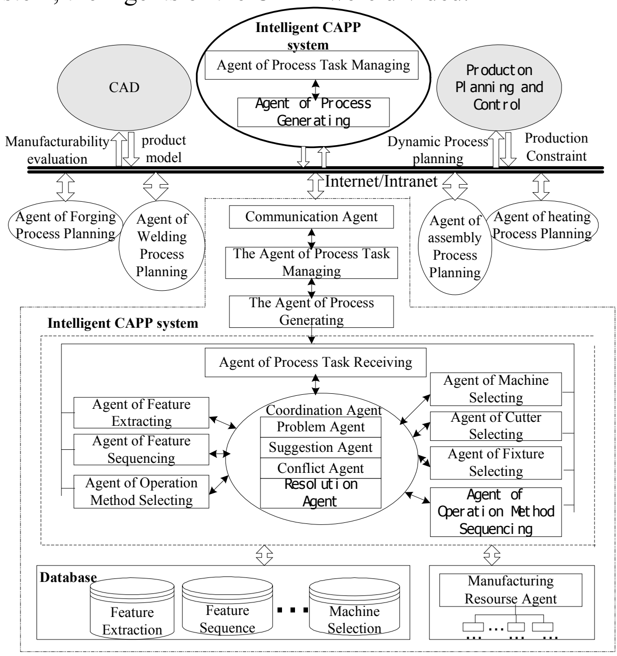


Figure 1. Structure of the intelligent CAPP system based on MAS

(1) The Agent of Process Task Management (PTM-Agent): It managed the decomposition and distribution of process planning task, tender and bid management, document management and authorization management.

(2) The Agent of Process plans Generating (PG-Agent): it generated process plans for the part, and integrated with PPC system. It also included nine two-level Agents which were the Agent of process task receiving, the Agent of feature extracting, the Agent of manufacturability evaluating and the Agent of feature sequencing, the Agent of operation method selecting, the Agent of machine selecting, the Agent of cutter selecting, the Agent of fixture selecting, the Agent of operation method sequencing.

(3) Coordination Agent (C-Agent): It resolved the conflicts between Agents in intelligent CAPP system. It includes four two-level Agents which are Agent of process managing, Agent of advice managing, Agent of conflict managing and Agent of problem solution generating.

(4) The Agent of Knowledge Management (KM-Agent): It Managed knowledge base, and it could obtain knowledge from outer resource (e.g. domain expert or database).

(5) The Agent of Manufacturing Resource Management (MR-Agent): It was responsible for managing and coordinating the scheduling and distribution of the resources that CAPP system needed. It included several two-level Agents, such as machine management Agent, tool management Agent, fixture management Agent, and so on. And each two-level Agent included many three-level Agents. For example, machine management tool Agent includes milling machine Agent, grinding machine Agent, lathe Agent, and so on.

(6) Communication Agent (Co-Agent): It is responsible for the communication between intelligent CAPP system and other systems (e.g. computer-aided design system, production planning and control system) in concurrent engineering environment.

PTM-Agent released the process task information to the Agent of process task receiving (PTR-Agent), which belongs to PG-Agent, and then PTR-Agent put the information into problem region of C-Agent. C-Agent received process task information from PTM-Agent, and then put the information into its problem region, then it issued information to other Agents and broadcasted process design task. After all the Agents that took part in the process design activity received the information, they would match the task with their abilities and feedback the match information to C-Agent. The Agents which had ability to resolve the process task started their works according to their abilities and status, and generated solutions of process planning and put them into advice region of C-Agent. After each Agent accomplished its mission, it would report the finishing status to C-Agent. If there were no conflicts between the advices which are generated by Agents, then all the advices would be combined to form the perfect solution. If there were some conflicts among the solutions generated by Agents, then the conflicts and the information of Agents that generated conflicts would be put into conflict region, and then the C-Agent adopted conflict resolution strategy to resolve them, at last, the complete process plans of the part were obtained.

The intelligent CAPP based on MAS is a dense knowledge, Each Agent has its domain knowledge, their tasks, evaluation rules, and domain knowledge for the same part are different, when they cooperate to generate the process plans, there are conflicts between the Agents. In order to resolve the conflicts between the Agents, the work mechanism and conflict elimination strategy for intelligent CAPP should be investigated.

III. THE CONFLICT ELIMINATION MECHANISM OF INTELLIGENT CAPP SYSTEM

The intelligent CAPP system is a system with highly concentrated knowledge, there are various conflicts in the intelligent CAPP system. Because of the complicacy of the conflicts, it is difficult to provide a kind of method that can resolve all conflicts automatically. In this paper, the conflict elimination strategies based on knowledge was adopted, including conflict elimination based on Rule-Based Reasoning(RBR) and Case-Based Reasoning(CBR).

A. *Conflict Elimination by Rule-based Reasoning*

During the production in the enterprise, there are the knowledge of manufacturing method selection, the knowledge of manufacturing resource selection and constraint knowledge, and so on. For example, the knowledge of manufacturing resource selection can be denoted in the form of three- element group:

R=(F-Name, OpM, M-Resource): F-Name is the manufacturing feature, OpM shows the manufacturing method, M-Resource indicates the manufacturing resource, such as machine, tool and fixture. During the selection process of machine, tool and fixture, a manufacturing feature may correspond to several machines, tools and fixtures, there is one-to-many relation between the manufacturing feature and the manufacturing resources. Take example for the drilling, the corresponding machine could be a CNC vertical milling machine (M1), a vertical lift table milling machine (M2) or a drilling machine(M3), so the knowledge of machine selection can be expressed as (hole, drilling, M1or M2 or M3), which provides the resolution possibility for the conflicts produced in the decision process of process planning.

The constraint knowledge can be described by use of four-element group:

T=(Con-Name, Con-Content, Con-Type, Con-Property): Con-Name is a constraint object name; Con-Content is the constraint content, Con-Type shows the constraint type, Con-Property shows the attribute of the constraint knowledge.

The attributes of the constraint knowledge can be divided into two categories: tight constraint and loose constraint. The tight constraint must be satisfied, such as positioning constraint, clamping constraint, preference relation constraint of manufacturing feature, and so on. While loose constraint can be flexed under the definite condition, so it also can entitled the scalable constraint. For example, during the manufacturability evaluation, the planner suggest the constraint knowledge of the bore's length to diameter ratio as (hole, constraint for structure processing property, $L/R \leq 5$, loose) in the sight of manufacturability, when there are the conflicts between this constraint knowledge and the designers' function knowledge, it could be loosened as (hole, constraint for structure processing property, $L/R \leq 6$, loose). then the conflict can be solved by replacing the current constraint knowledge using a loose constraint that is compatible with the designers' function knowledge.

In the process of cooperating to generate process plans, the domain knowledge is expressed in the form of rule, the conflicts which the Agents generated in MAS were resolved by use of these rules under inference mechanism. When the method of RBR is used to resolve the conflicts, there are many methods to describe knowledge, one of the methods to express conflict rule is defined.

R=(R_{ID}, Conflict-Content, Conflict-Resolution, Conflict-Type)

R_{ID} shows the rule number, Conflict-Content indicates the conflict content, Conflict-Resolution denotes the method of conflict solution, Con-type shows the conflict type. Take the example for the drilling, what the Agent of the machine selection chooses (hole, drilling, M1). When the Agent of tool selection evaluates the suggestion of the Agent of machine selection, by calculating the driving power based on the chosen tool and the principal axis speed, the situation that principal axis' power can't be satisfied with the demanded productivity is detected, so there is a conflict between tool selection and manufacturing time. Here the solution which the tool selection Agent chose is to "keep the productivity", the manufacturing productivity is the tight restriction, the Agent of machine selection must take some relevant measures to ensure the manufacturing productivity, the conflict elimination strategy which it adopts is to "select another machine". The rule about the machine selection can be described as:

RID=rule30, Conflict-Content=scarcity of principal axis's driving power, Conflict-Resolution=choosing another available machine, Conflict-Type=manufacturing time conflict.

There are two optional solutions for the Agent of machine selection. By calculating, M2 can satisfy the productivity demand and save energy. Consequently, the solution which is received by negotiating is (hole, drilling, M2).

B. *Conflict Resolution by Case-based Reasoning*

The work mechanism of CBR is similar with human's cognition, CBR supports description and memorization of experiences, and has the strong expansibility and self-adaptive capability. When knowledge can't be expressed and rule can't be extracted, the method of CBR is very effective to resolve the conflicts between the Agents. Multi-Agent dynamic coordination for collaborative design was studied in [7], and conflict elimination based on CBR in cooperative design was depicted in [8]. In the process of conflict elimination based on CBR, the experiences were stored to construct case library. When a new problem needs to be resolved, the cases that are similar with the new problem are obtained by indexing the case library, the new problem may be solved by modifying the relevant contents of the case. The process of conflict resolution based on CBR is described in intelligent CAPP based on MAS.

(1)Part description: Describing the feature, and the location relationship between the features and features' attributes of the new part, the model based on feature of the part not only includes geometry information but also process information including tolerance, surface finish and material of the part. In the intelligent CAPP, the features were divided into the compound feature and the simple feature, the simple feature is single surface, it is step-face or curved face. The compound feature is made up of more than two faces, they are boss, slot and hole, and so on. In order to identify the location between the features, the relationships between the feature and the first reference plane was divided into vertical, parallel, non-vertical and non-parallel, when the part was modeled by use of feature.

The relationship between the interference features was defined to be three types.

1) BB interference: The two interference features have the common boundary face.

2) BR interference: The boundary face of one feature is the reference face of another face.

3)RR interference: The two features have the common reference face.

(2)Part indexing: The features of the new part and their relevant location relationships were used to index the case library, the old parts similar with the new part are discovered to form the candidate case set. It is supposed that the feature set of the part P_{new} which generated process plan conflict is defined to be $F_{Pnew,i}=\{a_1, a_2, \ldots, a_m\}(i=1,2,3\ldots m)$, the feature set of the indexed old part P_{old} is $F_{Pold,j}=\{b_1, b_2, \ldots, b_n\}(j=1,2,3\ldots n)$, the similar value between P_{new} and P_{old} is calculated, the old part with the maximal similarity value would be chosen. The similarity value of the two features is calculated by using (1).

$$S_1 = \frac{1}{2m}\left(N_{1i} + N_{2i}\right) \qquad (1)$$

m: the number of the features that the new part generating process plan conflict posses

N_{1i}: the number of the same features between P_{new} and P_{old}, $N_{1i}=\{x \mid x\in F_{Pnew,i}\cap F_{Pold,j}\}$.

N_{2i}: the number of the location relationship match between the same features of P_{new} and P_{old}. When the relevant feature of P_{new} and P_{old} have the same location relationship, $N_{2i}=1$. Otherwise, $N_{2i}=0$.

It can be proven that the similarity value of feature S_1 ranges from 0 to 1, i.e., $S_1\in[0,1]$. By use of (1), the old parts in the case library is searched out to form case set.

(3)Feature matching: The attributes of the same features are matched between the new part and the old part in the case set, the features and their location relationships of the old parts are similar with the features and their location relationships of the new part, the old parts are sequenced according to S_1. If there are some old parts whose features and the feature location relationships are near to the new part, the new part would be farther matched by use of the feature attribute similarity value, it is supposed that number of the same features between the new part and the old part is m, the similarity of feature attribute is defined as (2).

$$S_2 = \frac{\omega_{\dim ension}S_{\dim ension} + \omega_{tolerance}S_{tolerance} + \omega_{finishe}S_{finish}}{\omega_{\dim ension} + \omega_{tolerance} + \omega_{finish}} \qquad (2)$$

$S_{dimension}$: the similarity value of the geometry dimensions between P_{new} and P_{old}.

$S_{tolerance}$: the similarity value of tolerance for the matching features between P_{new} and P_{old}.

S_{finish}: the similarity value of face finish for the matching features between P_{new} and P_{old}.

$\omega_{dimension}$, $\omega_{tolerance}$ and ω_{finish} stand for the weights of geometry dimension, tolerance and face finish respectively.

$$S_{\dim endion} = 1 - \frac{1}{ml_1}\sum_{i=1}^{m}\left(\sum_{k=1}^{m_1}\frac{\left|F^{new,i}_{\dim endion,k} - F^{old,i}_{\dim endion,k}\right|}{\max\left(F^{new,i}_{\dim ension,k}, F^{old,i}_{\dim ension,k}\right)}\right) \qquad (3)$$

$$S_{tolerance} = 1 - \frac{1}{ml_2}\sum_{i=1}^{m}\left(\sum_{l=1}^{m_2}\frac{\left|F^{new,i}_{tolerance,k} - F^{old,i}_{tolerance,k}\right|}{\max\left(F^{new,i}_{tolerance,k}, F^{old,i}_{tolerance,k}\right)}\right) \qquad (4)$$

$$S_{finish} = 1 - \frac{1}{ml_3}\sum_{i=1}^{m}\left(\sum_{p=1}^{m_3}\frac{\left|F^{new,i}_{finish,} - F^{old,i}_{finish,}\right|}{\max(F^{new,i}_{finish,}, F^{old,i}_{finish,})}\right) \qquad (5)$$

m: the number of the matched features between P_{new} and P_{old}.

l_1: the number of the relevant geometry dimension for the matching features between P_{new} and P_{old}.

l_2: the number of the relevant tolerance for the matching features between P_{new} and P_{old}.

l_3: the number of the main manufacturing faces for the matched features between P_{new} and P_{old}.

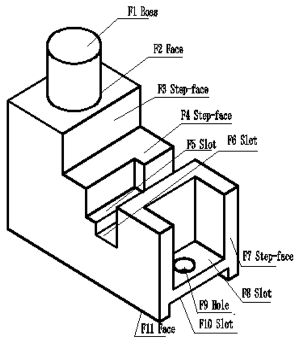
It can be proven that the similarity value of the geometry dimensions ($S_{dimension}$) ranges from 0 to 1, i.e., $S_{dimension}\in[0,1]$. In like manner, $S_{tolerance}$□[0,1]and S_{finish}□[0,1]. Equation (3)-(5) are put in (2), $S_{feature}$ between P_{new} and P_{old} could be obtained, and $S_{feature}$□[0,1].

(4)Sequencing: The old parts are sequenced according to the similarity value $S_{feature}$.

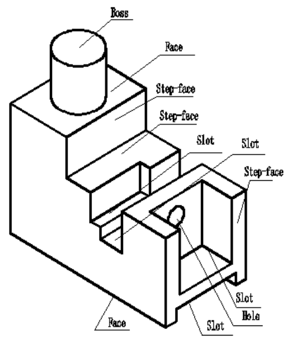
(5)Result checking: If the old part that is indexed satisfies the requirements, that the process plan conflict of the new part would be resolved, and the result is put in the case library to be new example at the same time. Otherwise, the unsuccessful reasons are analyzed, and the new part would be modified by the design department.

IV. CASE ILLUSTRATION

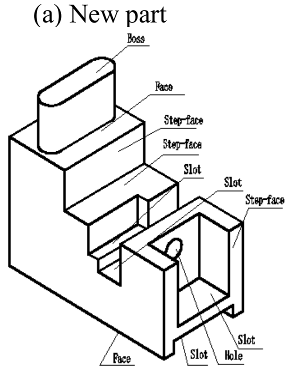
In the process of modeling the part based on feature, Pro/E was developed by use of its TOOLKIT to build the feature model of the part. In practice, the author applied visual c++ and SQL Server to develop the module of the conflict elimination based on CBR. The new part was shown in Fig.4(a), the Agent of sequencing feature extracted its features in the process of generating process plans, and sequenced the features according the preference relationship under certain process constraints, which included location constraint, benchmark constraint, set-up constraint, non-destructive constraint, and main prior to the minor constraint, and so on. The reasonable sequence of the features should meet the preference relationship constraints.



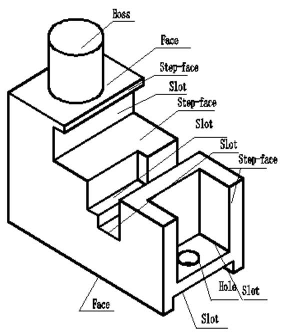
(a) New part



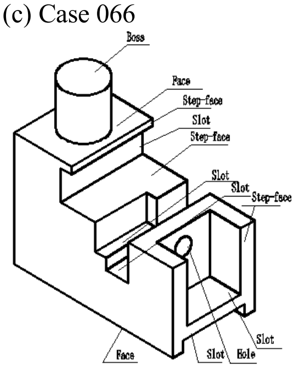
(b) Case 035



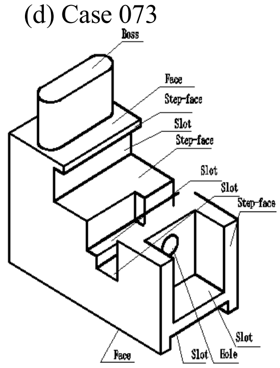
(c) Case 066



(d) Case 073



(e) Case 051

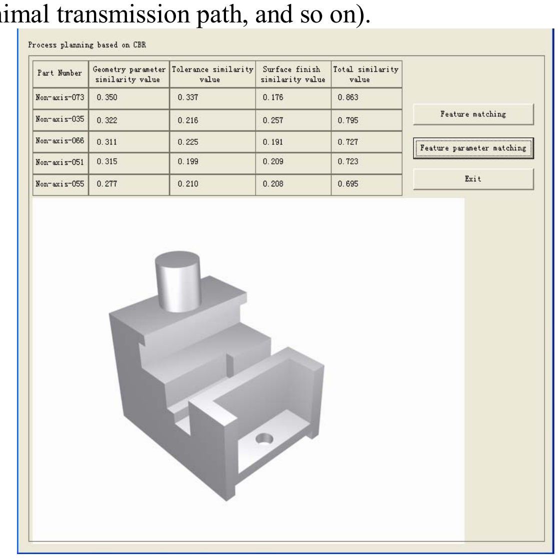


(f) Case 055

Figure 2. Case part drawing

Based on the above-mentioned constraints, the Agent of feature sequencing sequenced the features of the new part, the result was F11→F10→F1→F2→F3→F4→F5→F6→F8→F9→F7, and the sequence result was put in suggestion area of the C-Agent. Then the Agent of operation method selecting estimated the sequence result according to manufacturability knowledge, including process property and operation economy of the part, it found that the sequence result of the feature was reasonless, thus the conflict occurred between the Agent of sequencing feature and the Agent of operation method selecting. In order to resolve the conflict, the Agent of operation method selecting put forward suggestion that was to “sequence the features over again”, this suggestion was put in conflict area of C-Agent. Because the new part was non-axisymmetric, and it had many interference features, it was difficult to sequence the features correctly by use of the Agent of sequencing feature, thus the C-Agent gave a suggestion that was to “reason by use of CBR”.

Firstly, feature match was carried out by using (1), the five parts were searched in the case library, as shown in Fig. 2. Secondly, the feature attributes between the new part and the indexed parts were matched, and the similarity value of each the cases was calculated by use of (2)-(5), as shown in Fig.3. According to the calculation result, the similarity value between the new part and number case 073 was S_2= 0.863, its similarity value was biggest, and this part was most suitable for the new part. Then the planner modified the process plans of case 073 to manufacture the new part. If the planner only utilizes the case to decide the feature sequence, the Agent of selecting machine also continues to select the suitable machines for the feature. At last, the Agent of sequencing operation sequences operations based on optimization objective (minimum manufacturing time, minimal transmission path, and so on).



Part Number	Geometry parameter similarity value	Tolerance similarity value	Surface finish similarity value	Total similarity value
Non-axis-073	0.350	0.337	0.176	0.863
Non-axis-035	0.322	0.216	0.257	0.795
Non-axis-066	0.311	0.225	0.191	0.727
Non-axis-051	0.315	0.199	0.209	0.723
Non-axis-055	0.277	0.210	0.208	0.695

Figure 3. Conflict elimination based on CBR

V. THE CONFLICT ELIMINATION MODEL BASED ON KNOWLEDGE

The intelligent CAPP system’s conflict elimination model based on knowledge was depicted in Fig.4, which consisted of the following three modules: conflict detection, conflict classification and conflict elimination.

During the conflict elimination, conflict detection module detected whether the conflicts were existed, and the conflicts were registered in C-Agent. Conflict classification module labeled conflict categories on the basis of conflict information which was recorded by conflict detection module. Conflict elimination module found out the conflict elimination strategy and brought forward the solution method. Conflict elimination module adopted two kinds of resolution strategies including rule-based reasoning and case-based reasoning. Firstly, the conflict elimination strategy based on RBR was applied to obtain the conflict resolution, if the conflict has complicated relation and high coupling degree, it is difficult to solve the conflicts by use of rule-based reasoning, afterward the conflict elimination method based on CBR would be applied to solve the conflicts between the Agents, the conflict resolution method could be obtained by matching new conflict with the old conflicts in the conflict case library, the similarity coefficient between new conflict and the old was calculated the solution method of the old conflict which had the maximal similarity coefficient was adopted and modified, as in Fig.3.

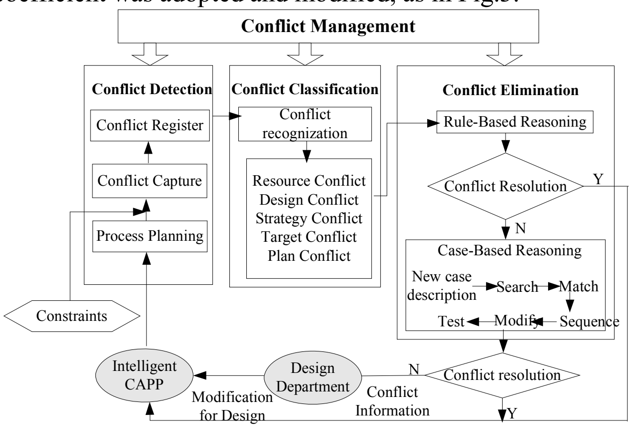


Figure 4. The conflict resolution model of the intelligent CAPP

VI. CONCLUSIONS

The intelligent CAPP system based on MAS decomposed the complicated process plans into a series of sub-questions by use of Cooperative Distributed Problem-Solving, and assign sub-questions to each Agent. The process plans would be accomplished by the cooperation among Agents. The CAPP system based on MAS has the following good characters:

(1) Each Agent has its own inference engine and knowledge base, and can ratiocinate independently. They have the capacity of reusability and expansibility, then the system structure of CAPP based on MAS could be changed according to the user's requirements.

(2) The intelligent CAPP system based on MAS can be conveniently integrated with other systems including CAD, CAM, PPC, and so on. In addition, it can be integrated with non-manufacturing process plans (suck as cast, forge, weld, heat processing and assemble) and distributed manufacturing process plans, which was illustrated in Fig.1.

(3) The system is modularized by a series of collaborated Agents, the difficulty to develop the system is reduced, the expansibility and the adaptability to different environment are strengthened.

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