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A Routing-Based Dynamic Workflow

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Abstract: The changes in dynamic workflows are various, such as role-based dynamic workflows, resource based dynamic workflows and so on. A routing-based dynamic workflow is proposed in this study and Agent technology is introduced into workflow management systems. At the environment only with initial and objective active nodes, route and terminal nodes can be autonomously chosen based on a routing algorithm to optimize the routing selection of workflow processes, so the method proposed in this study can optimize workflow management systems.

Key words: Dynamic workflow, routing, Agent, routing selection, routing agent

INTRODUCTION

Workflow technology has been deployed and well accepted in a great diversity of environments such as software engineering, health care, finance, production, office automation and banking (Bradbury *et al.*, 2004; Zhu *et al.*, 2004). But there are so many uncertain factors in enterprise business processes that workflow processes become uncertain. Traditional workflow management systems can not adapt the variability of real business processes; even can not adjust themselves in time according to the changes of activities because of shortage of flexibility. And existing dynamic workflow mechanisms can not allow the business processes to achieve the most optimized. In order to make some adjustments it is necessary to introduce new technology into the existing dynamic workflow management systems.

In recent years, agent has become more important in the field of artificial intelligence and computer science, because of its self-adaptability, autonomy, interoperability and traceability, etc. (Long *et al.*, 2009). If these characterizes of agent can be made good use and applied to the workflow management systems, then activities in the workflow management systems can collaborate with each other, so the current workflow management will be optimized. At the same time, a set of data can be delivered to the destination safely, reliably and speedy because routing algorithm is introduced into the internet. If a

routing algorithm can be made good use in the workflow management systems, the workflow processes will be optimized.

In order to improve the performance and efficiency of workflow management systems and solve the problem of poor flexibility of the current workflow technology (Long *et al.*, 2009), Agent technology is used to record the dynamic workflow's routing information because of its features such as intelligence, autonomy and flexibility, as well as routing algorithm is used to select the right route. In this way Agent technology and routing algorithm will be applied into the workflow management systems, so that a new dynamic workflow technology is proposed and the flexibility of workflow management systems is improved.

WORKFLOWS AND WORKFLOW NETS

Over the years, there are many different definitions of workflows, but there is not a unified definition. Overall, a workflow is composed of activities which are interconnected by workflow control structures specifying control flow among activities (Son and Kim, 2000).

A workflow model is the abstraction of a workflow as well as the abstraction of business process, describing how the processes are carried out. One of the most important things in dynamic workflows is how to build a workflow model which can adapt the dynamic changes. In this study, Agent technology is introduced into the

workflow model, using the features of Agent such as autonomy can characterize the dynamic changes of workflows preferably.

A workflow net (Van der Aalst, 1996; Du *et al.*, 2007) is a directed net which is composed of workflow processes and there is no dead node in the workflow net (Du *et al.*, 2008; Du and Jiang, 2008), in other words, starting from any activity, can reach one of the terminal activities. A workflow net consists of places, transitions and directed arcs. In the net a circle stands for a place; a rectangle stands for a transition; the directed arcs connect a place to a transition or connect a transition to a place. But there is no arc which connects a transition to a transition or connects a place to a place. In the workflow net, a place stands for the state of a current job; a transition stands for the implementation of an activity. In this study, activities will be divided into two categories, one of which named active place represent a state of an activity, AS represents the active place in the database. The other is branching place, the emergence of which can avoid the connection between transitions or places, but has no real meaning. ASt represents the branching places in the database. At the same time, in this study the weights of an arc no longer represent consumption and generation of the resources, but represent the time consumed by the running of a transition. The consumption and generation of resources are given in the routing table.

AN AGENT-BASED WORKFLOW MODEL

Agents are software entities that perform some sets of tasks on behalf of users with some degree of autonomy (Othman *et al.*, 2007). In recent years, Agent has been well accepted with the following properties (Wooldridge and Jennings, 1995).

Autonomy: Agents operate without the direct intervention of humans or the others and have some kind of control over their actions and internal states.

Social ability: Agents interact with other Agents (and may be humans) via some kind of Agent communication language.

Reactivity: Agents perceive their environment and respond in a timely fashion to changes that occur in it.

Adaptive: Agents make plans according to the requirements and constraints of target and environment, modify their goals and plans when the environment changes.

Because of these characteristics of Agent, it is very significant to introduce Agent into workflow management systems. In this way, workflow management would be more intelligent and autonomous. In this study, each activity in the workflow process corresponds to an intelligent Agent. Taking advantage of the intelligence, selection of the next activity is autonomous. At the same time, these Agents record the corresponding activity’s routing relation with other activities and interact with their neighbors in time in order to update their routing information, so that we can choose a reasonable path autonomously using the routing algorithm and based on the relevant records of the corresponding intelligent Agent.

When building a workflow management system for an enterprise, the entire enterprise is described as an Agent federation. Each activity is corresponded with an intelligent Agent, so the whole system can be regarded as an Agent federation. In the system, information is exchanged between Agents, so the system is more coherent. Furthermore each intelligent Agent is an independent entity in the workflow management system. The Agent can complete the update independently and deliver the relative information to the neighbors, notify its neighbors to make some update. There are also an intelligent Scheduling Agent, an Artificial Agent and some Resource Agents in the system. Overall Fig. 1 shows an Agent-based workflow model.

The main function of each component in the Fig. 1 is as follows:

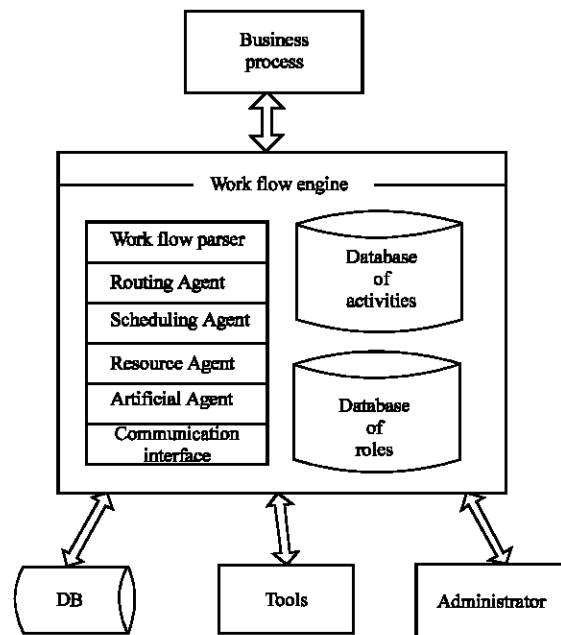


Fig. 1: An Agent-based workflow model

- **Scheduling Agent:** When the business process executes an activity, but the activity can not find a suitable following activity from the routing table, it will resort to the Scheduling Agent. At this time, the Scheduling Agent analyzes the current state of the activity as well as the requirements on the following Agent, then find out the matching activities through traversing the database of activities and update the routing table of the activity. If there is no matching activity in the database, the Artificial Agent will be fired to add the matching activity
- **Resource Agent:** It is responsible for the usage of resources in the workflow net, such as printers and database. When an activity plans to use some resources, it must give a request to the relevant Resource Agent. The activity can not use the resources until the relevant Resource Agent agrees with the request. The Resource Agent adopts the principle of First-come First-served, in other words when there are many activities asking for the right to use the resource, the activity giving the request at first will be given the priority to use the resource
- **Routing Agent:** It is the core of workflow management system and is responsible for the routing options
- **Artificial Agent:** The Artificial Agent in the workflow model plays the role of administrator. When there are some exceptions during the executed process of workflow instance and the Scheduling Agent can not resolve them, the Artificial Agent will be fired. The Artificial Agent will make the feedback to the administrator through the communication interface, then the administrator resolve the problem and deliver the proposal to the Artificial Agent through communication interface
- **Database of activities:** All of the activities are stored in the database of activities. Routing Agent and activities have the relation of one-to-one, in other words each activity corresponds to a Routing Agent which records the routing information of this activity
- **Database of roles:** All of the roles are stored in the database of roles. There is correlation between roles and activities. Each activity corresponds to a role, but a role corresponds to several activities. So when the workflow is running, the coordination among the roles must be paid attention

The system model shown in Fig. 1 is adopted in this study. The business processes in the model are developed by the enterprise. The initial and terminal activities are presented when the business model was developed. The most optimized path is chosen by Routing

Agents according to the routing information. The staff imports the initial and terminal activities into the entrance of workflow management systems (Long *et al.*, 2009) and then is transformed into a workflow instance by a workflow engine. At first the workflow parser parses and initializes the workflow instance and then the workflow instance is executed from initial activity to terminal activity by the Routing Agent. In this process, the Resource Agents are fired when some resources are needed, the Scheduling Agent is fired at first when there are some exceptions and the Artificial Agent is fired when the exceptions can not be resolved by the Scheduling Agent, the Routing Agent is updated at last.

Through this model, the Agent technology was introduced into the workflow management systems, the dynamic nature of workflow was implemented preferably if the Agent features such as intelligence and autonomy are made best use of to realize the intelligence and autonomy of workflow management systems.

ALGORITHM OF ROUTING SELECTION

The process definition of workflow models will be made at first. All of the activities and paths are included into a directed-weighted net, the nodes in the net present the activities, the directed arcs present the paths, the weighted values present the time consumed by the execution of activities. In order to express the relation between activities clearly, the special symbols in the Fig. 2. (Van der Aalst and Van Hee, 2002) are presented to express the multiply path selection.

In Fig. 2, the structure AND-split expresses such a situation that the completion of transition *t*'s precondition have an effect on all the post-conditions of *t*. The structure AND-join expresses such situation that the post-condition of transition *t* can be executed only when all the preconditions of *t* are completed. The structure OR-split describes that when the precondition of

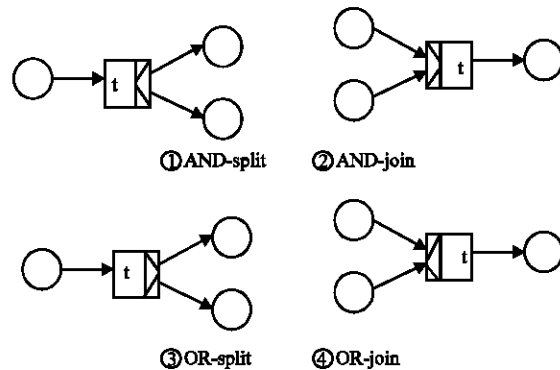


Fig. 2: Several basic structures of the workflow net

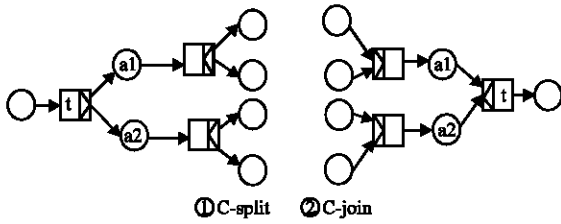


Fig. 3: The combination of basic structure

transition t was completed, only one post-condition of t can be executed; The structure OR-join describes that when one of transition t 's preconditions was completed, the post-condition of t can be executed.

At the same time, there are such situations in workflow net. The post-condition of an activity is more than one and the relations between them are different. Some of them are dependent with each other, in other words, if the preconditions were finished all of these activities will be executed together. But there are also activities which have the same preconditions, but when the preconditions were completed, only one of them can be executed. The combination of AND-split, AND-join, OR-split, OR-join in Fig. 3 will be used to describe these situations.

At first, in this study the places will be divided into groups, in this way the relations between activities can be expressed clearly. The activities in some groups are dependent with each other; the activities in the other groups are independent with each other. For example, when we apply for a loan to buy a house in the bank, the load can be handled by real estate, then a group of documents will be needed and the load can also be handled by individuals, then the other group of documents will be needed in this situation. In Fig. 3, a_1 and a_2 which do not have any real meaning are branching places, but in order to avoid the directed connection between two places. The C-split in Fig. 3 is the combination of AND-split and OR-split, describes that when the precondition was completed only one of the groups of post-conditions can be executed. The C-join in Fig. 3 is the combination of AND-join and OR-join, describes that the post-condition of transition t can be executed when all of the preconditions in one of the groups were completed.

When the staff inputs the initial activity, the system will choose the next route dynamically according to the algorithm of routing selection. When there are no suitable routes for choosing at the running time, the suitable active nodes will be added dynamically through the interaction between Routing Agent, Scheduling Agent and Artificial Agent. After that the corresponding arcs

and weights will be added to enrich the workflow net. In other words, the current workflow net need to update constantly through adding new arcs or new activities, all of these are completed by Scheduling Agent and Artificial Agent. When the business process run to an activity, it needs to conform whether the activity can be executed continuously. If it can be executed, the suitable and shortest time-consuming route will be selected from the routing table and the process will be continued. There are two potential reasons for the impossibility, one is that some preconditions of the activity do not completed, in this case, these preconditions will be executed. The other is that the resources are not enough, then the Resource Agent will be fired to coordinate the usage of resources.

Definition 1: A routing Agent is denoted by a 7-tuple $A = \langle ID, P, A, R, Res, Pre, TA \rangle$, where:

- ID is the name of a Routing Agent
- P is the description of the corresponding activity's role
- A is a finite set of the preconditions of the corresponding activity
- R is the resources and it's amount of the corresponding activity
- Res is the required resources of the corresponding activity
- Pre is the condition of the post-conditions of the corresponding activity
- TA is the corresponding routing table

The relation between activity and ID is one to one correspondence, in this way each activity can be found through ID. P is the description of the corresponding activity. Every activity needs some conditions to support its execution. There are several preconditions of an activity, so when the business process runs to an activity, it needs to check whether all the preconditions of the activity were completed. The activity can not continue if there are some preconditions uncompleted. The precondition needs to be executed before the activity when it was uncompleted. A is a finite set of the preconditions, $A = \{a_1, a_2, \dots, a_n\}$, where a_i ($i = 1, 2, \dots, n$) is the ID of activities. The implementation of each activity requires a number of resources and Res is the required resources of the activity, $Res = \{x_1 * r_1, x_2 * r_2, \dots, x_n * r_n\}$, where r_i is a specific resource and x_i is the amount of r_i . There are several relative activities of the current activity in the workflow net, but which one is the suitable post precondition? Based on this question Pre was introduced into this study to describe the conditions. There are not only resource constraints but also role constraints

Table 1: An example of routing table

Reachable activity	Objective activity	Needed resources	The produced resources	Description of post-condition	The consumed time
4	8	{3*a, 2*c, 6*r}	{2*a, c, 6*r}	D	15
2	8	{5*d, a, 3*c, 2*r}	{3*a, 2*c }	G	12
4	7	{a, 10*c}	{2*c, 6*c}	D	23
5	6	{4*d, 8*s}	{3*a, 2*d, 6*s}	A	56
3	9	{2*h}	{6*r}	F	31

included in the Pre, what's more, restricting rules of internal processes are included into the Pre. TA is the routing table of Routing Agent, the reachable activity of the current activity, the objective activity of each post-conditions, the needed resources of the post-condition, the resources can be produced when running to the post-condition, the description of the post-condition and the time spent by running to the terminal activity through this post-condition are all concluded in the Routing table. The description of the post-condition contains the description of the corresponding role and the description of the current state. The capital letters are used to indicate the available conditions of the activity. Res is the required resources of the corresponding activity, Res = {a*r1, b*r2, ..., x*rn}, x*rn shows that the number of resource rn is x. If the number of resource r is indefinite, it will be presented as ∞*r. TA is expressed as Table 1.

When the process runs to a certain activity, it is necessary to select the next activity according to the routing table and the algorithm of routing selection. The algorithm of routing selection is just as follows:

Algorithm 1: Algorithm of routing selection

```

B= the activity corresponding to the current routing table;
i= j= k= 0;
Step 1 for (every activity A in the routing table)
{
  if (A. objective activity = B. objective activity)
  { H1 [i] = A; i++; }
}
m = i;
if (m==0) go to Step 6;
Step 2 for (i=0, i<m, i++)
{
  If (H1 [i]. required resources< B. resources)
  {H2(j)=H1 (i); j++;}
}
n = j;
if (n==0) go to Step 7;
Step 3 for (i=0, i<n, i++)
{
  if (H2 [1]. Description of post-condition = B. Pre)
  { H3 [k] =H2 [i]; k++;}
}
p =k;
if (==0) go to Step 8;

```

```

Step 4 A = H3 [0];
  For (i=0, i<p-1, i++)
  {
    if (H3 [i+1]. required time < H3 [i]. required time)
    { A=H3 [i+1]; }
  }

```

Step 5 execute the activity A, update the routing table and relative information of Agent;

Step 6 launch the Scheduling Agent. The Scheduling Agent searches the activity which has the same objective activity with the current activity in the workflow net, add the activity to the routing table, then update the routing table and H1, go to Step 2;

if (the eligible activity was not found) go to Step 9;
Step 7 launch the Resource Agent. The Resource Agent coordinates the required resource of this activity with the method of first-come first-served, then update the routing table, go to Step 3

Step 8 launch the Artificial Agent. The administrator gets the feedback on the situation from the Artificial Agent at first. The new arcs will be added to the workflow net by the administrator and then update the routing table and H2, go to Step 3

Step 9 launch the Artificial Agent. The administrator gets the feedback on the situation from the Artificial Agent at first. The new activity or the new arcs will be added to the workflow net by the administrator and then update the routing table and H1, go to Step 2

In the algorithm, the set H1 of post-condition would be formed in the step 1, all the activity in H1 have the same objective activity with the current activity. If there is no activity satisfy the condition, skip to the step 6, then Scheduling Agent would be fired to search the matching activity from the whole workflow net with the method of breadth-first searching. The time complexity of step 6 is the activity number of the workflow net. If there is no activity matching the requirement, the Artificial Agent will be fired. In the step 2, the number of required resources would be checked, the activity meeting the resource requirement would be selected out and form the set H2, if there is no activity in H2, then skip to the step 7 and wait for the Resource Agent to coordinate the usage of all the resources. In the step 3, the qualification of each activity would be checked, all the activities meeting the requirements would be selected out from H2 and form

the set H3. If there is no activity in H3, skip to step 8, then the Artificial Agent would be fired and new activities or new arcs would be added to the workflow net.

APPLICATION

In the company, there are several approaches to deal with the same problem and the result will be different or similar. In order to have the most effective and optimized approach it is necessary to optimize the process of selection and make use of the workflow net. There is a simple workflow net in the Fig. 4 and there are four terminal activities in the workflow net.

Suppose that there is a business process, the initial activity is a1, the terminal activity is s1, the resources of a1 is {4* r1, 3* r2, 6* r3}. The corresponding routing Agent of a1 is A1 = {1, B, {a1, a8, a16, a18}, {4* r1, 3* r2, 6* r3}, {}, A, T1}. The routing table T1 of A1 is in the Table 2. According to the routing table, the suitable route will be selected.

The corresponding Routing Agents of activity a2, a8, a16, a18 are A2 = {2, A, {a3, a5}, {4* r1, 3* r2, 6* r3}, {r1, 2*r3}, Z, T2}, A8 = {8, L, {a9, a14}, {3* r1, 2* r2, 4* r3}, {r1, r2, 2*r3}, K, T8}, A16 = {16, U, {a17}, {4* r1, 6* r2, 3* r3}, {6*r1, 2*r3}, H, T16}, A18 = {18, G, {a19}, {6* r1, 8* r2, 3* r3}, {2*r1, 4* r2, 2*r3}, J, T18}. According to the algorithm of routing selection, the routing selection process is just as follows:

- Activities having the same objective activity with a1 are a2 and a8, H1 = {a2, a8}
- Activities which can satisfy the resource requirement of a1 in H1 are a2 and a8, H2 = {a2, a8}
- An activity meeting the conditions of a1 in H2 is a2, H3 = {a2}
- An activity having the shortest running time in H2 is a2
- Execute a2, update the routing table, the Routing Agent of a2 will be updated as A2={2, A, {a3, a5}, {4* r1, 4* r2, 6* r3}, {r1, 2*r3}, Z, T2}

Suppose that a process is running to an activity a6, the corresponding Routing Agent of a6 is A6 = {6, H, {s1}, {3* r1, 5* r2, 7* r3}, {2* r1, 2* r2, 6* r3}, K, T6}, the corresponding Routing Agent of a7 is A7 = {6, K, {s1}, {2* r1, r2, 3* r3}, {4* r1, r2, 6* r3}, K, T7}. Table 3 is the routing table T6 of a6. When the process runs to a6, the preconditions of a6 are checked whether all of them are executed. If there are some unexecuted preconditions, a6 will wait for the complement of the preconditions. According to the algorithm of routing selection, a routing selection process is just as follows:

- An activity having the same objective activity with a6 is a7, H1 = {a7}
- But there is no activity in H1 which can satisfy the resource requirement of a6, so H2 = {}

Table 2: Routing table of a1

Reachable activity	Objective activity	Needed resources	The produced resources	Description of post-condition	The consumed time
a2	s1	{ r1, 2*r3}	{r2}	A	20
a8	s1	{ r1, r2, 2*r3}	{r1, r2}	C	34
a8	s2	{ r1, r2, 2*r3}	{ r1, r3}	D	21
a16	s3	{6*r1, 2*r3}	{4*r1, 2*r3}	E	16
a18	s4	{2*r1, 4* r2, 2*r3}	{3*r1, 2*r3}	F	24

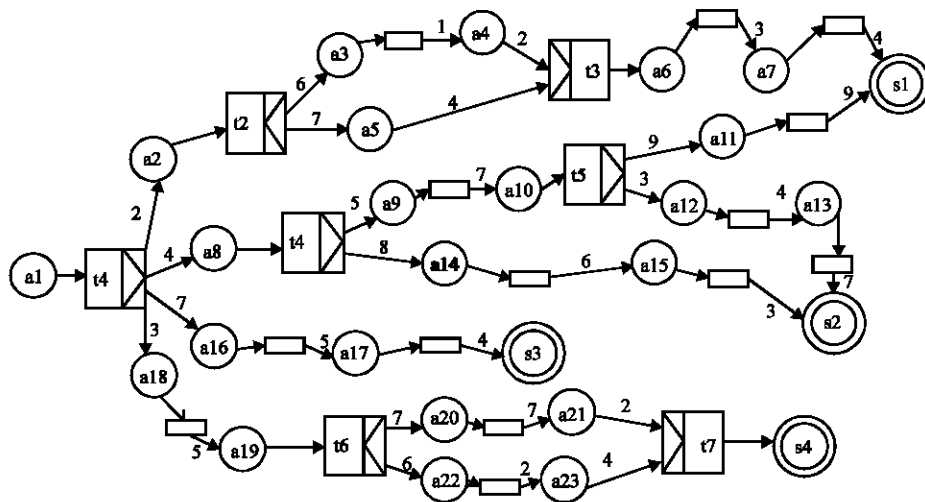


Fig. 4: A simple workflow net

Table 3: The routing table of a6

Reachable activity	Objective activity	Needed resources	The produced resources	Description of post-condition	The consumed time
a7	s1	{4* r1, r2, 6* r3}	{2* r1, r2, r3}	K	7

- Launch the Resource Agent, coordinate the usage of resources. When the resources satisfy the requirement, the routing table will be updated, at this time the resources of a7 are {4* r1, 2*r2, 6* r3} and H2 will be updated as {a7}
- An activity which can meet the conditions of a6 in H2 is a7, H3 = {a7}
- An activity having the shortest running time in H2 is a7
- Execute a7, update the routing table and the Routing Agent of a7 was updated as A7={6, K, {s1}, {4* r1, 2*r2, 4* r3}, {4* r1, r2, 6* r3}, K, T7}

Run in this way, until running to the terminal activity s1.

Every activity in the workflow net in Fig. 4 can run to one of the terminal activity, in other words, there are no dead activities in the workflow net. When searching the objective activity, it concludes several situations.

- There is one or more paths which can reach the objective activity, according to the algorithm of routing selection, the objective activity can be reached when the former five steps were completed and there is no need to launch the other Agent
- The objective activity cannot be reached because there is no suitable path. At this time, the Scheduling Agent will be fired and suitable activity in the workflow net will be found out and relative arcs will be added to the workflow, then the routing table will be updated, after that the relative Routing Agent will be updated too
- The objective activity cannot be reached because there is no activity satisfying the requirement. At this time, Artificial Agent will be launched, suitable activity and relative arcs will be added to the workflow net and then the routing table will be updated; the relative Agent will be updated too
- The objective activity can not be reached because there are not enough resources. At this time the resource Agent will be launched to coordinate the usage of resources

So, the objective activity can be reached when starting from any activity.

CONCLUSIONS

With the development of Agent technology, it has been widely used in various fields. The application of

Agent has increased the intelligence and autonomy of some software greatly. Internet's success also shows the importance of routing selection. A dynamic workflow model based on algorithm of routing selection was proposed in this study and the Agent technology was introduced in this model. Taking advantage of Agent such as intelligence and autonomy can optimize the dynamic workflow extremely and the flexibility of routing selection can be improved greatly.

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