Research on Optimization of clinical Pathway Execution based on Multi-agent Simulation

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Abstract—**The clinical pathway execution is a complex system engineering related to multidisciplinary or multi-department collaboration such as examination, laboratory test, operation, nursing, etc. This paper has proposed a multi-agent based simulation method from the hospital system level, and some key technologies including simulation model specification for hospital system, patient behavior model specification based on clinical pathway, and the multi-agent simulation model scheduling mechanism are discussed.**

Keywords-clinical pathway; multi-agent simulation; simulation model specification; patient behavior modeling; simulation scheduling

I. INTRODUCTION

With the increasing medical needs brought by the aging population and social development, how to ensure and continuously improve quality of medical care, standardize treatment behavior, control and reduce medical costs, has become key problems which governments and medical institutions need to solve. After ten years of medical reform, we have made great achievements, but it's still difficult and expensive to get medical service, especially in large general hospital. Clinical pathway is considered to be an effective way to alleviate this problem under the current conditions, and therefore has attracted widespread attention. Clinical pathway[1,2] is a group of treatment plan developed by medical experts according to specific evidence-based medical guidelines for a range of targets around patient, and these tasks have a specified time period and describes specific disease diagnosis and treatment process, which can facilitate to standardize the medical treatment, reduce medical costs, enhance the patient's satisfaction.

II. PROBLEM DESCRIPTION OF CLINICAL PATHWAY EXECUTING OPTIMIZATION

The execution of clinical pathway is a complex, multidisciplinary or multi-department collaboration system engineering, involves in multiple activities including lab, exam, operation and treatment, which should be disposed by certain sequence, and any delays or balk will influence the executing effects of clinical pathway. The scheduling of treatment activities in existing clinical pathway management system is relatively fixed and rigid, mainly according to given template, and the orders is disposed by staff randomly without any decision optimization support. Therefore, when there is a number of parallel cases sharing the limited medical resources, how to determine the disposal sequence of treatment activities, identify the starting and ending time of individual treatment to improve the resources utilization ratio, reduce the medical cost, produces the optimal scheduling problem of electronic clinical pathway, which involves in hospital medical resources allocation optimization and treatment activities scheduling optimization, also is the important and difficult problem in clinical pathway management.

III. RELATED RESEARCHES

Clinical pathway is introduced into china in 1996, and in 2009 the national ministry of health began to extend clinical pathway application to national hospital. But due to the lack of understanding of clinical pathway, and corresponding policy environment, and multidisciplinary collaboration experience, and other reasons, the spread and development of clinical pathway has met many difficulties [3, 4]. Domestic research has mostly focused on clinical pathway effects evaluation from the point of view of management, rarely on clinical pathway executing optimization from the engineering perspective, and abroad pay more attention to the engineering method of clinical pathway management.

Clinical pathway originates from industry field, so many scholars use systematic engineering and industrial engineering to study the execution of clinical path optimization problem [5-6]. Wolf [7] has proposed a mathematical programming model with constraints for clinical pathway and pointed out the difficulty of the clinical path optimization, which involved the trade-off of multiple clinical indicators. Other researchers [8-11] have introduced hybrid genetic algorithm into clinical pathway scheduling to optimize the execution of the routine diagnostic activities, which has only considered the local human resources constraints and mainly been for single or multiple clinical pathway scheduling in specific departments. Aiming to

multiple clinical pathway execution at the same time and multi-level resource optimization requirements, Brecht [12-13] proposed a assessment method based on discrete event simulation for multi-level clinical pathway, which can meet combination and hierarchical modeling and simulation requirements of clinical pathway, which has been used for planning of surgical department medical facilities (such as the operating room). Elena [14-15] expounded the hierarchical features of clinical pathway execution and established a discrete event simulation model for hospital surgery department, then introduced 0-1 optimization method into operation room planning to simulate and analyze surgery patient queue and the recovery room bed utilization ratio.

In summary, above engineering methods have studied clinical pathway optimization scheduling problem most from the perspective of a single department, rarely from the level of the hospital system or multiple disciplines or departments coordinative aspects, but optimal of clinical pathway execution in single department does not guarantee overall optimal of hospital operational effectiveness.

IV. OPTIMIZATION METHOD OF CLINICAL PATHWAY EXECUTION BASED ON MULTI-AGENT

A. Multi-agent Simulation Method for Clinical Pathway Execution Optimization

To resolve the optimization problem of clinical pathway execution from the hospital system level, there are several difficulties:

- The complexity of medical activities. It's difficult to describe the relationship between patient, medical resource, medical action and their influences to the final diagnosis and treatment results.

- The complexity of patients' illness. It's difficult to describe the consultation process, because every patients' illness is different in thousands of ways.

Multi-agent simulation method and the electronization of clinical pathway have provided ways to solve these problems. Multi-agent simulation method for clinical pathway execution optimization uses multi-agent simulation method to construct hospital's medical system simulation framework, uses clinical pathway to describe the behavior of patient agent normally, and uses optimization algorithm to optimize the patient's medical behavior and the resource distribution, finally run the agent models and evaluate the effect of clinical pathway and resource's utilization ratio according to the simulation result data.

B. Key Technologies

1) Multi-agent m&s framework of medical activities

Multi-agent M&S framework of medical activities (shown as Figure 1) is used to describe the agents, resources and their interactive relations related in medical activities. The optimization problem of clinical pathway execution is to fix out how to distribute medical resources between patients from the system level, and there are three factors: medical resources, patients and resource distribution rules. Accordingly, there

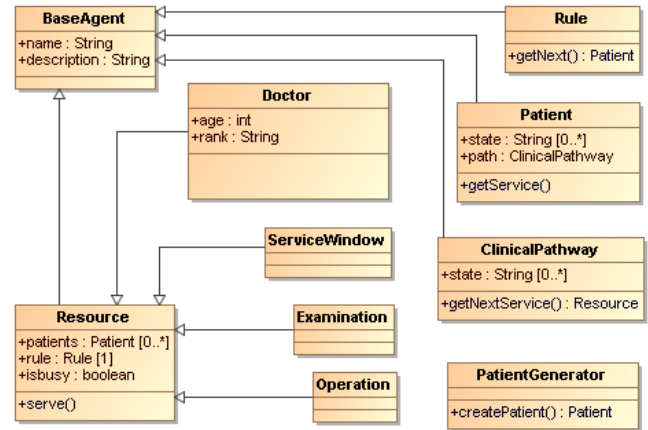three types of agent model in the framework: resource agent, patient agent and the rule agent.

FIGURE I. MULTI-AGENT M&S FRAMEWORK

Resource agents represent the medical resources provided from hospital to the patients, including doctors, service windows, medical equipment etc. This type of agents have name, id, description, state and current service object as their main attributes. The main behavior of these agents is to get new patient agent from rule agent and provide medical services after given service to the last patient agent.

Patient agents represent the patient who come need diagnosis and treatment. This type of agents have name, illness and case as their main attributes. The behavior of these agents is to ask for specific medical resources according to the medical pathway.

Rule agent represent the rules used to distribute medical resources, for example the examination and operation equipment. These agents have name, service queue, request queue, resource distribution algorism as their main attributes. The behavior of these agents is to accept patient agent's service request, sort the requests according to the resource distribution algorism, finally allocate the patient agent which has highest priority to the free resource agent to do medical service.

2) Clinical pathway modeling based on process ontology

The complex dynamics of patients' condition and treatment behavior is the difficulty of simulation and optimization analysis, and clinical pathway can be used as a standardized means used to describe the treatment behaviors of all kinds of patients. The key parts of clinical pathway mainly include time, care and intervention measures, prognosis standards, and mutation records. Current modeling technology research on clinical pathway mainly divided into two categories: one is from the perspective of clinical pathway management information system modeling and process analysis, focusing on the diagnosis and treatment process modeling, general process modeling methods, such as workflow modeling, Petri net modeling, dynamic workflow modeling, etc. Due to the process modeling tools and methods differ in thousands ways, it is not conducive to clinical pathway sharing and simulation analysis; another kind is from the perspective of knowledge sharing,

focusing on the medical knowledge representation of clinical pathway. Most of these studies focus on static relationship expression of clinical pathway in treatment activities. In our research, the clinical pathway is modeled with process ontology modeling, which can both facilitate knowledge sharing and process analysis of the clinical pathway, show as Figure 2.
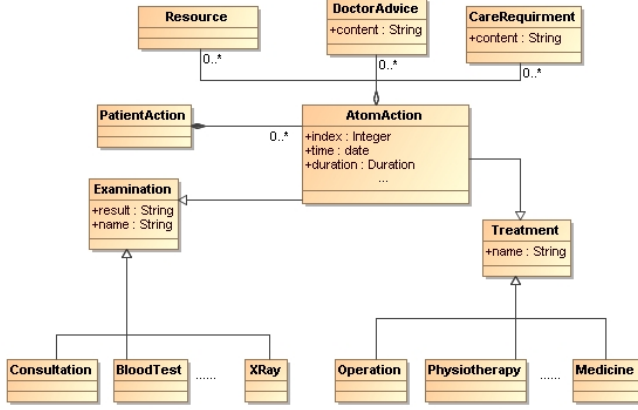

FIGURE II. ONTOLOGY META-MODEL FOR PATIENTS' BEHAVIOR

3) Simulation schedule method based on the time step

Simulation schedule based on time step use integer to push the simulation time, usually from 0 to 1, 2, 3 etc. Every agent model has a determined time unit, this time unit specific the model behavior cycle. Agent model's behavior is triggered every time step. Different agent model could use basic step unit to automatically transfer the time to support the description and combination of agent behavior model in multi time scale. Following algorism shows the detail.

Algorithm: agent Simulation Strategy

(1) Initialize

    i.   Set start time t0 and end time tf of the simulation;

    ii.   Set every environment variable to its initial value;

    iii.   Set every agent to its initial state;

(2) Set current simulation time to t0;

(3) If current simulation time ≤ tf, goto step 4; or else, goto step 6

(4) Update the states of agents and environment variables

for j = 1 to n (n is the total number of agents)

Execute the agent's behavior (moving, reasoning, communication and learning etc.) according to the states of environment variables and other agents;

Update the states;

Handle the environment change;

Handle the birth and death of agents;

endfor

(5) Advance the simulation clock and goto step 3;

(6) End the simulation.

There are three types of agents need to schedule: Resource Agent, Patient Agent and Patient Generator Agent, and Figure 1 gives the details.
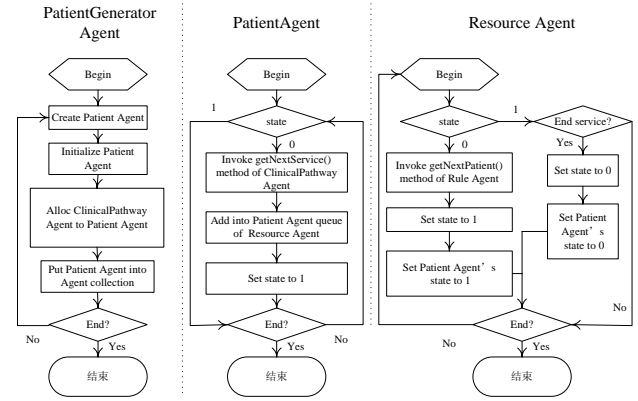

FIGURE III. AGENT SCHEDULE PROCESS

V. CONCLUSION

Aiming at the optimization problem of clinical pathway execution and to optimize the clinical pathway execution effect, improve the utilization ratio of medical resources and optimize the allocation of resources, an analysis method based on multi-agent simulation is proposed from the hospital system level to further strengthen the simulation engineering methodology and key technologies research on clinical pathway execution from the point view of systems engineering. With emerging multi-agent simulation and clinical path modeling as the main research way, the paper has developed corresponding hospital system simulation model specification, patient behavior model specification, and the multi-agent simulation model scheduling mechanism from the system level, which can provide engineering methodology guidance for resource optimization configuration and treatment process analysis in the process of clinical pathway execution.

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