Human Resource Behaviour Simulation in Business Processes

Hanwen Guo[1], Ross Brown[2], Rune Rasmussen[3]

Abstract: The structure and dynamics of a modern business environment are very hard to model using traditional methods. Such complexity raises challenges to effective business analysis and improvement. The importance of applying business process simulation to analyze and improve business activities has been widely recognized. However, one remaining challenge is the development of approaches to human resource behavior simulation. To address this problem, we describe a novel simulation approach where intelligent agents are used to simulate human resources by performing allocated work from a workflow management system. The behavior of the intelligent agents is driven a by state transition mechanism called a Hierarchical Task Network (HTN). We demonstrate and validate our simulator via a medical treatment process case study. Analysis of the simulation results shows that the behavior driven by the HTN is consistent with design of the workflow model. We believe these preliminary results support the development of more sophisticated agent-based human resource simulation systems.

1 Introduction

At the operational levels of a business, sets of procedures govern the logical and temporal organizations of physical tasks into workflows. Such procedures are implemented as workflow management systems that guide the operations of a business [1]. In many cases, workflow simulation systems [2] can inform the problem of creating optimal workflow models. Firstly, the workflow simulation, in the "as is" phase, identifies, represents and maps daily activities, choices, resources, messages and processes in an organization as simulation models. Typically, a resource is either a human resource or non-human resource [3]. The human resource and their behaviour are defined according to their roles and affiliations. With non-human resources, the model defines properties of objects. Then, the workflow simulation, in its "to be" phase, runs these simulation models to generate simulation results. The analysis about simulation results provides people with insight about bottlenecks and weaknesses in processes. In workflow simulation, these simulation models must be very carefully represented and communicated, which ensures that both experts and stakeholders can understand simulation targets and modelling results.

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Despite the fact that we understand what workflow simulation can do, ineffective simulation approaches are frequently used. Van der Aalst et al state that we have already failed in the “as is” phase, where mature human resource modelling approaches are missing [4]. While concerning the “to be” phase, they note that many workflow simulations start the simulation at an abstract state. This is not suitable for managers to solve concrete problems at the operational level. In addition, we noticed that there is another flaw evident in workflow simulation. The representations of simulations are very useful for experts in workflow, but stakeholders state these representations disrupt their understanding about workflow simulation [5, 6]. The major reason for this flaw is that stakeholders are conditioned to real personnel arrangement of physical objects, rather than the abstract representation of models and [5-7]. Thus, the communication of human resource modelling in simulation is still problematic. This introduces risks in transferring resource model knowledge to stakeholders and analysts.

We believe that 3D visual simulation techniques, such as 3D Virtual Worlds, can provide superior insight into a workflow simulation. A 3D Virtual World is a replication of the real world, where every object in it has a 3D representation, and users can interact with these objects. Such a richer environment is better able to demonstrate human work via the clear visual representation of agent behaviours, see Fig.1. Projects have shown that the applications of 3D Virtual Worlds is very useful for educational and professional training needs in the Military [8] and Healthcare domains [9], however, only a few researchers [10, 11] have applied this approach in workflow simulation.

Fig. 1. Snapshot of an emergency treatment workflow visualized in a 3D virtual world, where four avatars are about to revive an injured person.

In this paper, we focus on the human resource behaviour modelling issue to begin the process of developing a comprehensive simulation approach. To our best knowledge, only a few researchers have conducted research on this topic [4]. We present a human resource centric simulator, which involves a society of intelligent agents that collectively form a multiple agent system. The Hierarchical Task Network (HTN) is an automatic planning algorithm that is used to solve problems by forming and executing sequenced actions [12]. We employ it to imitate human resources solving assigned workitems. Two rigorous validation techniques [13] prove the behaviour of intelligent agents is rational, and therefore viable as a human behaviour simulation system.

The paper is organized as follows. Section 2 covers in more detail related simulation approaches and intelligent agent applications. Section 3 introduces our simulator. Section 4 validates and demonstrates our simulator with some simulation scenarios. Section 5 concludes our work and discusses our future work.

2 Related Work

Our work combines aspects of workflow simulation and intelligent agents. The following subsections discuss these two concepts in further details.

2.1 Simulation Approach

Traditional simulations are categorized as simulations that use native resource behaviour modelling, incomplete process modelling approach and less support simulation at the operational level [4].

With respect to the resource behaviour modelling aspect, Van der Aalst et al. [4] proposed a model to calculate how an individual human resource allocates working time on tasks. Their model can integrate with Petri-Net based WfMS to estimate the total consuming time of whole business processes.

Modern WfMSs record performed activities in system logs. Many researchers [14-16] advocate that a process mining tool ProM can be utilized to effectively build process models. Rozinat et al [17] proposed a simulation framework to tackle the other two pitfalls. They use ProM to rediscover workflow models from logs, and merge these workflow models with current state of the workflow system to generate a near future scenario.

In this paper, our agent-based simulation approach focuses on tackling two pitfalls. We designed a HTN based state transition to model human resource behaviour, driving intelligent agents in the simulation. The behaviour of intelligent agent is recorded in system logs, whereby ProM can be used to rediscover some workflow models in the simulation. Examined simulation models can be provided to assist people in simulated decision making at operational level.

2.2 Intelligent Agent Applications

The term *intelligent agent* can be explained as an autonomous entity that can sense the environment where it locates and acts upon its senses to change the environment [18]. A set of intelligent agents form a Multi-Agent System (MAS), where they coordinate and co-operate with each other to accomplish a global goal.

O’Brien and Wiegand [19] advocate that combining MAS with WfMS can enhance workflow management. Researchers [20, 21] advocated that MAS are suitable for modelling organizational structure and solving resource allocation in hospital environments. This is due to the fact that a hospital consists of many individual medical divisions.

In the light of this research [20, 21], an agent-oriented approach should be a viable method for optimizing resource utilization [22] in a healthcare application. However, none of them have addressed modeling human resource behaviours in workflow systems. Moreover, there is no work that utilises 3D Visualisations as a comprehensive simulation approach. To this end, we aim to establish an agent approach as a critical step towards fully simulating and visualizing human resource behaviour using a 3D virtual world approach.

3 Human Resources Centric Simulator

This section discusses details of the human resource centric simulator. Firstly, it defines responsibilities of intelligent agents by analyzing simulation requirements. Then, it describes a HTN based transition mechanism that is used to drive intelligent agents to simulate human resources. Lastly, it describes the implementation of the presented design.

3.1 Simulator Architecture

In daily work, WfMS allocate workitems to resources, provide resources with an interaction platform according to the organizational structure, and records the behaviour of resources in logs that can be used for analysis and process modelling. Therefore, we believe that this simulator must satisfy the following requirements:

- Agents should formulate their society, that is, they should replicate the real organizational structure
- Agents should emulate human resource behaviour according to the responsibilities of human resources, interacting with WfMS
- Agents should record their behaviour in logs, which is the basis of analysis.
- Agents should be flexible and implemented easily; so that they can provide any WfMS with a simulation component, especial a legacy WfMS

Considering the first three requirements, we identify four types of intelligent agents, namely *Resource Manager Agent*, *Resource Agent*, *Customer Agent* and *Auditor Agent*. Regarding the last requirement, we believe these intelligent agents should be competent to interact with the *workflow reference model* [23], which is a conceptual model that outlines the necessary components in a WfMS. An illustration of the simulation architecture is in Fig. 3. A detailed discussion about their social and individual aspects is in follows.

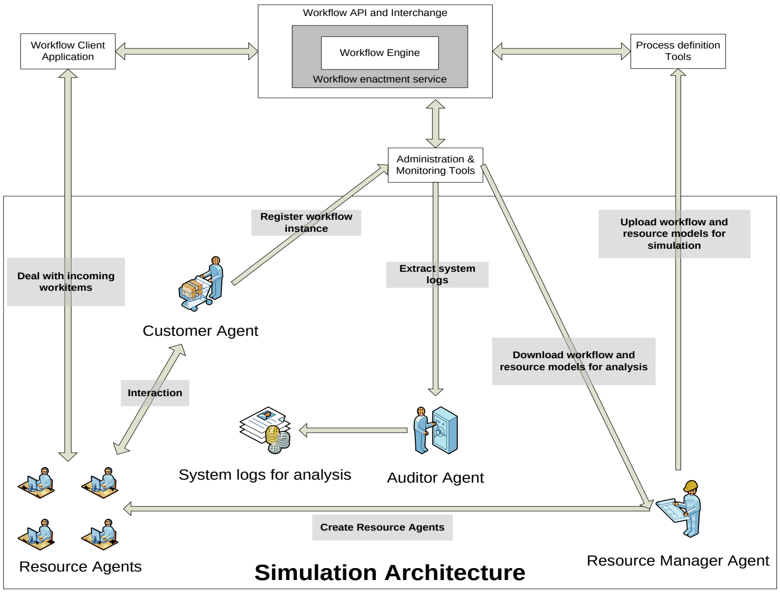

Fig. 3. Architecture of our agent-based simulator.

The Resource Manager Agent is in charge of replicating the workflow system. This agent downloads workflow and resource models from WfMS via Administration & Monitoring Tools. According to the simulation specification, it will modify workflow and resource models, and submit these modified models to the Workflow Engine via Process Definition Tools. At the same time, it creates a set of another type of Resource Agent to simulate human behaviour to fulfil the simulated organizational structure.

The Resource Agent simulates a human resource in the workflow system, processing workitems allocated by the Workflow Engine, and interacting with other agents. When dealing with an incoming workitem, it may require extra information from the Customer Agent for deciding its behaviour that is driven by a state transition mechanism. Another responsibility of the Customer Agent is to register workflow instances on the Workflow Engine according to a simulation specification. As whole workflow instances are accomplished, the Auditor Agent extracts logs, providing human simulation operators with analysis information.

3.2 HTN based State Transition Mechanism

In a workflow management system, behaviour of resources can trigger a state transition of a workitem. Russell et al [3] concluded that the state transition of a workitem is in a finite state set $\boldsymbol{\Omega}$, including, *created*, *offered*, *allocated*, *started*, *suspended*, *failed* and *completed*. These workflow transitions are known as *resource patterns*, illustrating the behaviour of resources in a workflow system. In this section, we discuss a Hierarchical Task Network (HTN) based state transition mechanism used to simulate the behaviour of human resources for triggering workitem state transitions on set $\boldsymbol{\Omega}$.

We adapted a formal representation of HTN in [12] and define it as a function $HTN\ = <\boldsymbol{w}, \boldsymbol{i}, \boldsymbol{D}(\boldsymbol{w}), \boldsymbol{A}>$ that returns a sequence of ground *actions* representing a plan for a workitem $\boldsymbol{w}$ that is going to be solved, where $\boldsymbol{i}$ is the initial state of $\boldsymbol{w}$, $\boldsymbol{D}(\boldsymbol{w})$ is function that iteratively decompose the workitem $\boldsymbol{w}$ as a set of ground primitive sub tasks, and $\boldsymbol{A}$ is the corresponding *action* set related to the decomposition of workitem $\boldsymbol{w}$. The execution of an action $a \in \boldsymbol{A}$, if the preconditions p of action a are satisfied, will finish a sub task and generate some effects e that may lead to a state transition of the workitem $\boldsymbol{w}$. The execution of these sequenced ground actions or plan will lead to its final state that is usually failed or completed in $\boldsymbol{\Omega}$.

We describe a brief HTN in Fig. 4. A Resource Agent will use the HTN to decompose and execute a workitem. Two assumptions have to be made to prevent a problem from becoming a none solution problem [24]. First, every primitive task in $\boldsymbol{D}(\boldsymbol{w})$ can find an action in A to resolve, always. Second, a workitem can be decomposed as a set of primitive tasks in finite iterations of the decomposition.

We use a workitem "receive a new patient" to illustrate our HTN based transition mechanism, see Fig. 5, where the workitem is decomposed as three primitive task sets **a**, **b** and **c**. The resolving of any primitive task set **a**, **b** or **c** will trigger the state transition of the workitem on set $\boldsymbol{\Omega}$. For example, in primitive task set **c**, "accept this work" indicates the *offered* state, "check the condition of this patient" and "check if another patient is coming" indicate this workitem is processing now, that is, it is in *started* state. If the preconditions of "notify another nurse" are satisfied, the Resource Agent may execute "notify another nurse", and then the current workitem "receive a new patient" may be in the *suspended* state. Lastly, "send this patient to ward" transitions this workitem to the *completed* state.

Part 1 Decomposition

1. Input a workitem w.
2. **IF** ($\boldsymbol{D}(\boldsymbol{w})$ returns a primitive task set)
{
Find the a sequence of actions σ in $\boldsymbol{A}$;
IF (preconditions of σ are satisfied)
Go to Step 6;
ELSE
Return failure;
}
3. Choose a non-primitive task t in $\boldsymbol{D}(\boldsymbol{w})$, whose preconditions are satisfied.
4. Let $\boldsymbol{w} = t$
5. Go to Step 2.

Part 2 Execution

6. For(each action a in σ)
{
Execute the action a and get the execution result;
Upload the result to workflow management system;
IF(Upload is successful)
Go to next turn;
}

Fig. 4. Procedure of the adapted HTN transition mechanism.

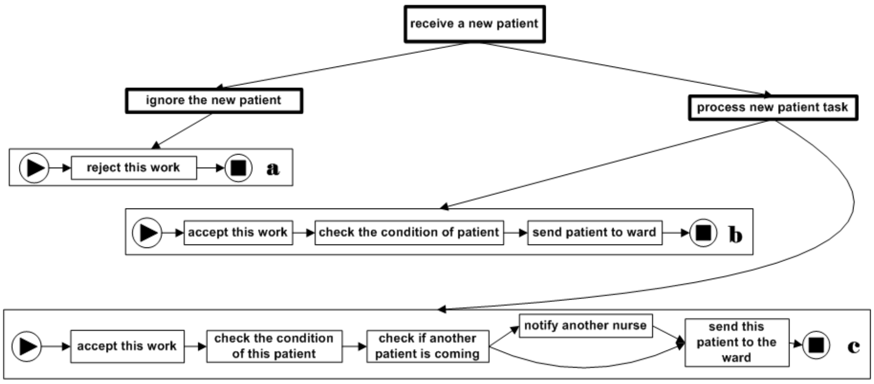

Fig.5. Graphical representation of decomposing the workitem "receive a new patient".

3.3 Simulator Implementation

We use the JADE platform to implement our simulator. JADE is a JAVA based agent platform, facilitating agent application development by providing developers with an agent system infrastructure platform. In practice, our simulator will interact with the YAWL system [25]. The YAWL system is a WfMS developed from the workflow reference model, which facilitates the implementation of a well structured simulation architecture.

4 Experiments

In this section, we discuss the validation methodology for and the validation results of our simulator. Then, we demonstrate the simulation ability of our simulator in a what-if scenario, which is intended to assist people in operational decision making.

4.1 Validation Methodology and Results

An agent system is modelled from both social and individual perspectives [26]. Thus, we select two suitable techniques, which are "*Comparison to Other Models*" and "*Traces*" from [13], to validate our simulator, aiming to provide evidence that the social and individual behaviour of the agents in this simulator is rational. We rename Comparison to Other Models to *Model Comparison* in the following paragraphs.

On the one hand, Model Comparison requires us to compare our simulation results with the other simulation results. In simulation, any result is the joint effort of every intelligent agent in the simulator. Thus, this technique validates the social aspect. On the other hand, Trace requires us to follow and analyse the behaviour of an individual intelligent agent in the simulator and determine if the logic of the target is correct, that is, it validates the individual aspect.

We additionally create a random simulator to facilitate these two techniques. The random simulator replaces the Resource Agent with the Random Agent, but still uses the architecture of a human resource centric simulator. The Random Agent will randomly select an action to transit a workitem from one state to another, without considering the current situation.

In practice, two simulators were validated in three adapted workflow systems [27-29], processing 20 workflow instances, respectively. Logs of two simulators were validated through the framework in Fig. 6.

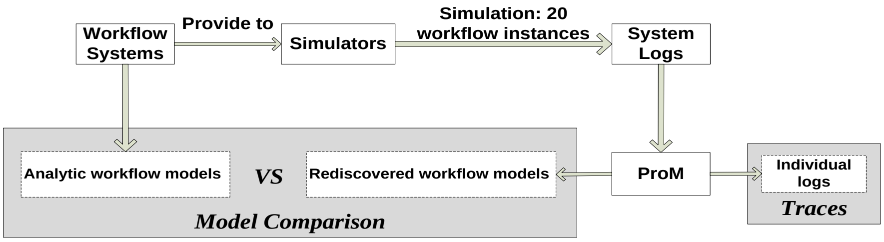

Fig. 6. Illustration of the validation framework. Simulators are provided with a number of workflow instances. System logs are extracted to rediscover models which are used for Model Comparison and Traces.

In Trace, abnormal state transitions are identified in the random simulator. We selected two workitems *Receive Patient* and *Transfusion* for demonstration. Although Random Agents can select actions to let a workitem transit from one state to another, they ignore what is a suitable action for the transition. Compared with Random Agents, Resource Agents can rationally select actions from knowledge.

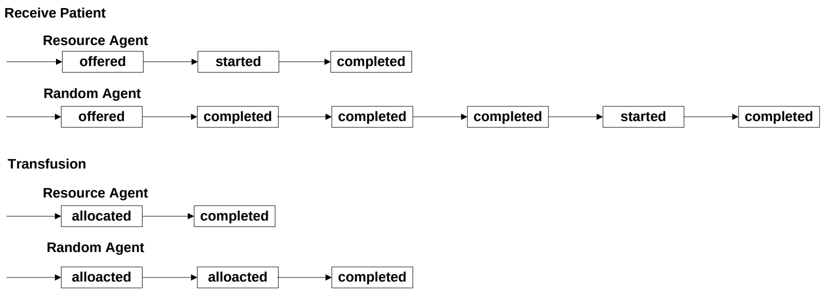

Fig. 8. Illustration of a fragment in systems logs, which represents a potential state transition sequence. It is apparent that the Random Agent cannot make a rational action in workitems where redundant states appear. Compared with Random Agent, there is no redundant state transition in the trace of Resource Agent.

In Model Comparison, workflow models rediscovered from the human resource centric simulator's logs are similar to analytic workflow models, however, significant discrepancies are found between the workflow models rediscovered from random simulator's logs and analytic workflow models. We select one adapted workflow system [27] for demonstration, see Fig. 7. The Model *A* is similar with Model *O*, only two transitions are missing. Considering the model *B*, we can tell that most of the transition is missing and a wrong transition is created.

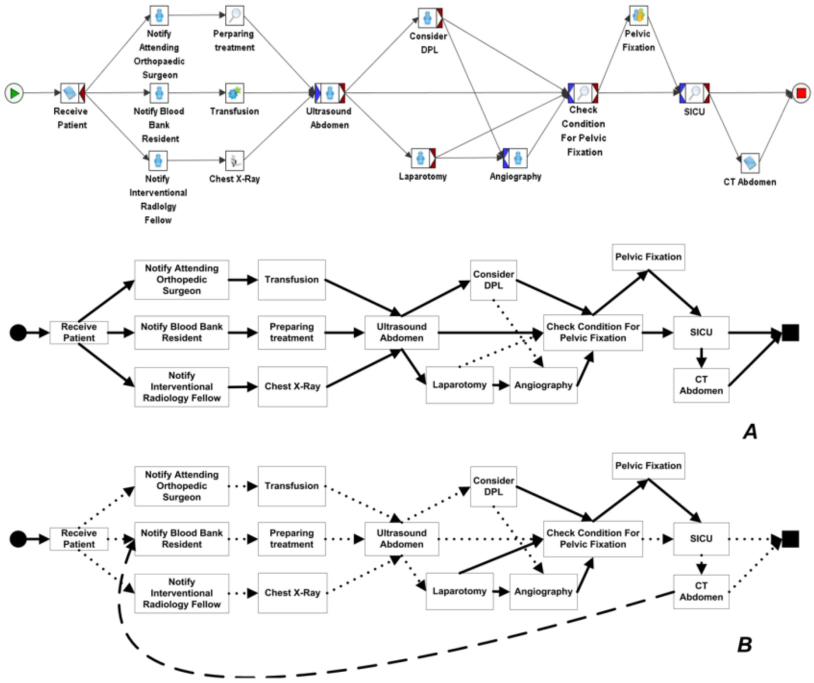

Fig. 7. Analytic model *O* and two rediscovered workflow models (*A* and *B*). Model *A* was rediscovered from the human resource centric simulator's logs, while model *B* was rediscovered from the random simulator's logs. Dashed lines indicate missing transitions and wrong transition.

With the investigation in Model Comparison and Trace, we believe the results provide supporting evidence that the human resource centric simulator is rational and it can be used as a basis for a tool to assist people in decision making.

4.3 Resource Agents Workload Analysis

With the positive result in the previous section, we will show the simulation ability of our simulator in a what-if scenario.

Let us consider that an administration department in a hospital is considering a personnel arrangement for a pelvic treatment process. The treatment process they selected is the Model *O* in Fig.7, and three candidate resource models for this treatment are available in TABLE 1. *Resource Model A* and *Resource Model B* both contains six human resources, but responsibilities of human resources are adjusted. Compared with *Resource Model A* and *Resource Model B*, there are two more human resources added in *Resource Model C* which intends to relieve workload on individuals

Table 1. Three candidate resource models.

Resource Model	Resource ID	Responsibility
A	staff_1	Laparotomy, Check Condition for Pelvic Fixation, Pelvic Fixation
	staff_2	Transfusion
	staff_3	CT Abdomen, Angiography, Chest X-Ray, Consider DPL
	staff_4 staff_5 staff_6	Receive Patient, Preparing treatment, SICU, Notify Orthopaedic Surgeon, Notify Blood Bank resident, Notify Interventional Radiology Fellow, Ultrasound Abdomen
B	staff_1	Prepare Treatment, Laparotomy, Check Condition for Pelvic Fixation, Pelvic Fixation,
	staff_2	Transfusion
	staff_3	CT Abdomen, Angiography, Chest X-Ray, Consider DPL, Ultrasound Abdomen
	staff_4 staff_5 staff_6	Receive Patient, SICU, Notify Orthopaedic Surgeon, Notify Blood Bank resident, Notify Interventional Radiology Fellow
C	staff_1	Laparotomy, Check Condition for Pelvic Fixation, Pelvic Fixation,
	staff_2	Transfusion
	staff_3 staff_7	CT Abdomen, Angiography, Chest X-Ray, Consider DPL, Ultrasound Abdomen
	staff_4 staff_5 staff_6 staff_8	Receive Patient, SICU, Notify Orthopaedic Surgeon, Notify Blood Bank resident, Notify Interventional Radiology Fellow

We provided our simulator with the workflow model and three resource models for the simulation. Then, we investigate the simulation results with ProM and estimated time consumption, see Table 2. As we can see, Resource Model B may be the best one for administration department, showing its advantages in both items of time consumption.

Table 2. Simulation results with three resource models.

Resource Model	Time Consumption					
	workflow instance			workitem		
	Min	Ave	Max	Min	Ave	Max
A	53	158	285	2	19.8	58
B	48	106	158	2	14.75	53
C	34	118	245	2	13.92	52

5 Conclusions

In this paper, we have proposed a human resource centric simulator. There are three main contributions in this work:

Firstly, to our best knowledge, this is the first agent-based simulation approach that utilizes the HTN base state transition mechanism to model human resource behaviour in a workflow system. Secondly, we provide a general agent-based simulation architecture that can be integrated with a generic WfMS. This means our simulation architecture can be implemented as a simulation component for any WfMS. Thirdly, a what-if scenario has indicated that our simulator can be potentially used as a decision support tool, and is therefore of interest of business analysts.

In our future work, we will extend this simulation system as a hybrid Multi Agent System (MAS) / 3D Virtual World simulation system. Such an interactive visualization will give extra resource model analysis support for business process analysts and enhances process model communication to stakeholders [10].

Acknowledgments

This research has been supported by Smart Service CRC in Australia.

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