Project Scheduling Based on Multi-Agent Systems

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***Abstract*—One of the most important and challenging issues in construction project management is to schedule activities to meet the construction project requirements under resource constraints. In this paper, we will concentrate on the development of a workflow scheduling system that can be applied in construction supply chains based on the interactions of entities/partners. Execution of workflows that handle physical parts in a construction project may depend on location. Although workflow management problems have been extensively studied for decades, location information of workflows has not been considered in existing literature. We propose a methodology that includes modeling of location-aware workflows in construction projects based on formal workflow models and develop a technique to transform workflow models to formulate and solve a project scheduling problem. We propose a framework to implement a prototype system based on a FIPA-compliant multi-agent system platform and Google API.**

***Index Terms*—location aware workflow, project scheduling, multi-agent system**

I. Introduction

As construction projects become larger and more complex in terms of scale, cost and time, effective construction project management is very important for the success of a construction company. There are several research issues in the management of construction projects. One of the most important and challenging issues in construction project management is the scheduling of activities to meet the requirements under resource constraints. Companies in a typical construction supply chain need to negotiate with each other to create a feasible schedule for a construction project. Development of a scheduling software system to support and facilitate cooperation and project scheduling between the partners of a construction supply chain is required.

Project scheduling is one of the fundamental functions of construction project management. Project scheduling often relies on network planning methods such as critical path method (CPM) and project evaluation and review technique (PERT). However, such traditional network planning methods cannot be applied to real construction projects. PERT and CPM are helpful scheduling techniques only when the project deadline is not fixed and the resources are not constrained. Many project scheduling methods [1]-[5] have been proposed. In [6], the authors reviewed meta-heuristics for project and construction management. They indicated that the existing studies to solve real project scheduling problems can be classified into the following categories: (1) time-cost tradeoff [7]-[9]; (2) resource allocation [10]-[12]; (3) resource-constrained project scheduling; (4) resource leveling [13]-[14]; and (5) integrated models that consider more than one category above [15]-[16]. However, these studies did not provide a framework for scheduling projects in a construction supply chain. In this paper, we will concentrate on the development of a project scheduling system that can be applied in a construction supply chain.

Execution of tasks that handle physical parts in a construction project may depend on location. Although workflow management problems have been extensively studied for decades, location aspect of workflows has not been considered in the existing literature. In this paper, we study how to exploit recent advancements in multi-agent systems (MAS) [17]-[21], information technologies (IT) [22]-[24] and geographic information system (GIS) to reduce cost and time in the development of location-aware workflow scheduling systems based on a sustainable architecture. We propose a methodology that includes modeling of location-aware workflows of construction projects based on workflow models, develop a technique to transform workflow models to formulate and solve a scheduling problem. We propose a framework to implement a prototype system based on a FIPA-compliant MAS platform and Google API.

Our solution methodology combines IT, MAS architecture with Petri net models, an effective model for modeling and analysis of workflows [25]-[27]. In our architecture, the workflow to be performed by an agent is represented by a workflow agent and each resource is

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modeled by a resource agent. In MAS, the most well-known protocol for coordination and negotiation is the contract net protocol (CNP) [28]-[29]. There are a lot of works on distributing tasks in MAS with CNP [30]-[33]. To endow each agent with the knowledge to perform location-aware operations in the workflows, we propose a location-aware timed Petri net (LTPN) model, which extends time Petri net, for each workflow agent and resource agent. The Petri Net Markup Language (PNML) [34]-[35] is used as the format for representing the Petri net models. The location information in LTPN is used to calculate the firing time information based on Google Distance Matrix API. Our approach uses a software module to formulate the project scheduling problem based on the LTPN models and the project requirements. The cost and time involved in the development of scheduling software can be significantly reduced. The workflow scheduling problem is solved based on interaction of a number of interrelated optimization agents. We adopt a FIPA-compliant MAS platform, JADE, which provides built in service publication/discovery capabilities, to realize our system.

The remainder of this paper is organized as follows. In Section II, we describe the location-aware workflow scheduling problem. We introduce our scheme in Section III. In Section IV, we propose our problem formulation and scheduling method based on location-aware workflow models. We present our implementation and a case study in Section V. We conclude this paper in Section VI.

II. Supply Chain Project Scheduling Problem

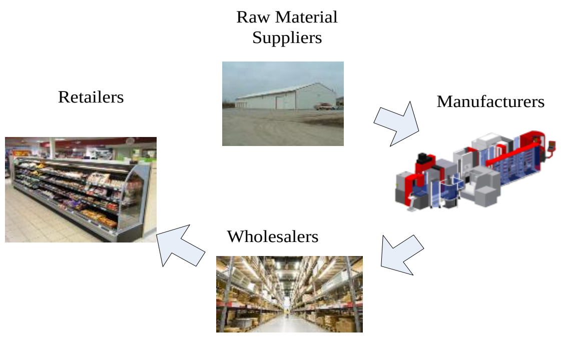

Figure 1. Example of a typical supply chain

A construction project usually relies on cooperation of a number of companies to manufacture and supply parts or components. These companies form a supply chain. Supply chain activities transform natural resources, raw materials, and components into a finished product that is delivered to the end customer. Fig. 1 shows a typical supply chain that provides parts or components. In addition to the supply chain that provides parts or components, companies that take part in a construction project also form a construction supply chain. Fig. 2 shows the configuration of a typical construction supply chain [36]. The participants of a typical construction supply chain need to negotiate with each other to create a feasible schedule for the given construction project. An important issue is to develop a software system to support and facilitate negotiation and cooperation between the partners of a construction supply chain. In this paper, we will concentrate on the workflow scheduling problem in construction supply chains. We will propose a flexible scheduling system to optimize the construction project schedule based on cooperation of partners of a construction supply chain.

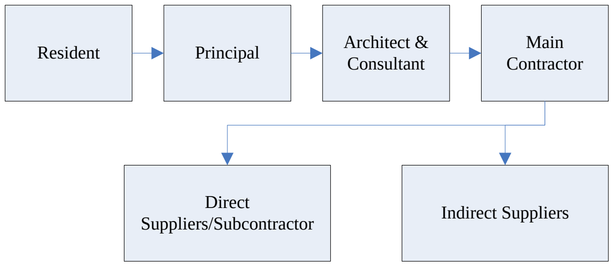

Figure 2. Configuration of a typical construction supply chain

Location information plays an important role in scheduling the activities and resources that move materials, parts or components from one partner to the next in a construction supply chain. Although workflow management problems have been extensively studied for decades, location aspect of workflows has not been considered in existing literature. In this paper, we will study how to develop location-aware workflow scheduling systems. The location-aware workflow scheduling system aims to find the schedule of resources and activities based on the location information of the entities in the system.

The entities in a construction supply chain can be classified into several categories: (1) orders that trigger the activities of a construction project, (2) activities that specify the operations to be performed for the fulfillment of construction project requirements and (3) resources that execute activities in a construction project. In this paper, a resource refers to construction equipment specially designed for executing construction tasks. Each entity has certain properties and makes decisions proactively and interacts with other entities. To propose a scheduling methodology based on MAS, we model each entity as an agent in multi-agent systems. Let $\boldsymbol{OA}$, $\boldsymbol{WA}$ and $\boldsymbol{RA}$ denote the set of order agents, workflow agents and resource agents, respectively. An order agent o has several attributes, (d_o, q_o, l_o), including order due date, demands and the location of the customer. A workflow agent n has the attributes, (t_n, l_n, w_n), to describe its workflow type, location and the structure of workflow. A resource agent r has the attributes, (l_r, a_r^k), to describe its location and the structure of activities that it can perform in the workflow. Given a set of entities $\boldsymbol{OA}$, $\boldsymbol{WA}$ and $\boldsymbol{RA}$, including orders, activities, resources and their associated location information, the problem is to optimize the schedule of each entity to meet the customers' order requirements such that the overdue cost can be minimized subject to (I) resource capacity constraints, (II) precedence constraints between the workflow agents and (III) demand constraints.

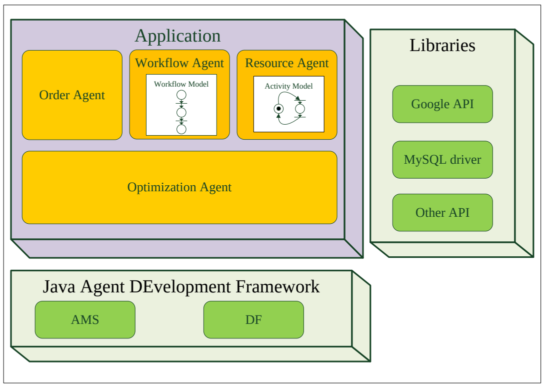

Figure 3. Architecture of the proposed scheduling system

Fig. 3 shows our architecture for the development of location-based workflow scheduling system. There are four types of agents, including order agents, workflow agents, resource agents and optimization agents. All these four types of agents are designed and implemented based on JADE, a FIPA-compliant MAS platform. Agents in Fig. 3 may invoke third party libraries such as Google API to obtain the processing time for location dependent operations in workflows. The location-aware workflow scheduling system is developed by applying a negotiation protocol between agents based on Petri net models of workflow agents and resource agents. A solution methodology will be proposed based on transformation of the Petri net models of workflow agents and activity models in this paper.

III. A Hybrid Scheme for Scheduling Location Aware Workflows

Our scheme to solve the location-aware workflow scheduling problem combines the contract net protocol (CNP) with optimization theories to optimize the schedules based on collaboration of workflow agents, resource agents and optimization agents. In CNP, an agent may play the role of a manager or a bidder. CNP specifies a four steps procedure to establish a contract between a manager and one or more bidders.

Step 1: The manager announces a task to the potential bidders.

Step 2: The potential bidders draw up proposals and submit the proposals to the manager.

Step 3: The manager awards the contracts to the best bidder(s).

Step 4: The awarded bidder may either commit itself to carry out the task or refuse to accept the contract.

As the original CNP only defines the interaction between one manager and multiple bidders, it must be extended properly to capture the interaction between the entities in a construction supply chain. In this paper, a multi-level CNP is proposed in this paper to capture the interaction between partners in a supply chain. The multi-level CNP can be applied in a supply chain to form a VE base on establishment of contracts between a set of workflow agents and a set of resource agents to fulfill order requirements. By combining CNP with optimization theories, our approach provides a flexible architecture to configure agents to achieve a goal. The negotiation protocol used in this paper extends the original CNP. Let's illustrate the multi-level CNP by an example.

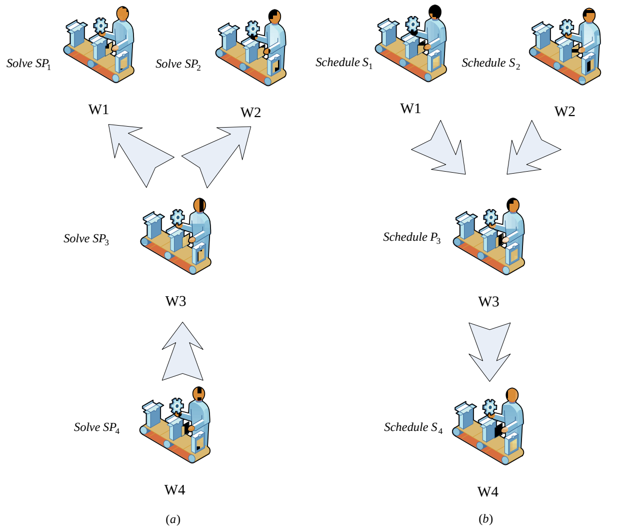

Figure 4. A hybrid approach based on combination of multi-level CNP and optimization algorithms

Fig. 4 shows how the multi-level CNP works for a construction supply chain network with four companies. Fig. 4(a) shows the task announcement messages propagate from the downstream to upstream in the supply chain. On receiving the messages, each company must solve the workflow scheduling problem. In Fig. 4(a), the workflow scheduling problem to be solved by company W_n is denoted as SP_n. Let S_n denote the schedule of company W_n. Each company draws up a proposal based on its schedule and then submits the proposal to its partner at the downstream as shown in Fig. 4(b). The downstream partner then decides whether to accept the proposal.

IV. Project Scheduling Based on Location Aware Workflow Models

Whenever a workflow agent needs to optimize the workflow schedule, a request will be sent to an optimization agent. The optimization agent will take two actions. First, it will automatically formulate the scheduling problem based on the requirements of the order agent, PNML models of the workflow agent and the relevant resource agents. Second, it will invoke optimization algorithms based on optimization theories to find good schedules for resource agents efficiently. Fig. 5 illustrates the flow chart for an optimization agent. There are three steps in the flow chart: (1) construction of agent models, (2) scheduling problem formulation based on extraction of parameters from the agent models and (3) application of algorithms for solving scheduling problem. As algorithms for solving scheduling problems have been extensively studied in the existing literature, we will only apply an existing algorithm in our proposed system. In the discussion as follows we will present the details of Step (1) and (2) only.

A. Step (1): Construction of Agent Models

In this step, the models for all workflow agents and resource agents are first created based on Petri net. An timed Petri net (TPN) G is a five-tuple $G=(P,T,F,m_0,\mu)$, where P is a finite set of places, T is a finite set of transitions, $F \subseteq (P\times T)\cup(T\times P)$ is the flow relation, $m_0 : P \rightarrow Z^{|P|}$ is the initial marking of the TPN with Z as the set of nonnegative integers and $\mu : T \rightarrow R^+$ is a mapping that specifies the firing time for each transition performed by RA. The marking of G is a vector $m \in Z^{|P|}$ that indicates the number of tokens in each place and is state of the system.

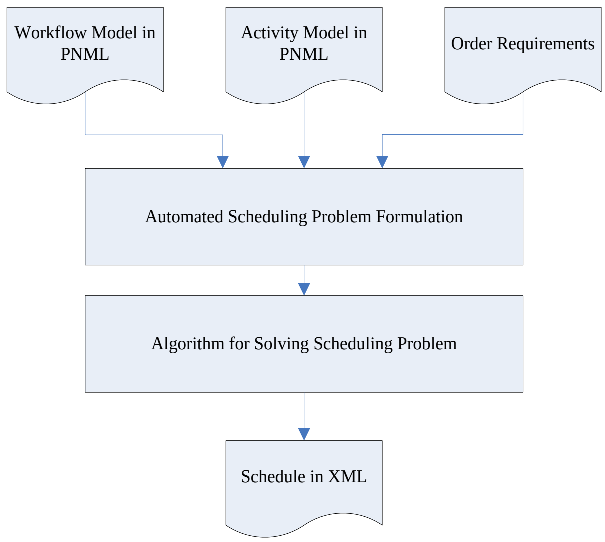

Figure 5. Dynamic workflow scheduling problem formulation and solution

As the original TPN model does not take location information into consideration, it cannot be used to describe location-aware workflows. In this paper, we extend the original TPN model by augmenting it with location elements for each place and transition to endow it with the capability to describe location-aware workflows. This new class of time Petri nets is called location-aware time Petri nets (LTPN). More specifically, a LTPN $GL = (P,T,F,L,m_0,\mu)$ is defined based on TPN $G=(P,T,F,m_0,\mu)$, where $L: P\cup T \rightarrow R^+ \times R^+$ s a mapping that specifies the location for each place and transition. In this paper, we use $L(p) = (x_p, y_p)$ to denote the location of place $p \in P$ and $L(t) = (x_t, y_t)$ to denote the location associated with transition $t \in T$.

In constructing the model of a workflow agent w_n, we use a subclass of LTPN called location-aware timed sequential Marked Graph (MG). A marked graph is an ordinary Petri net such that each place has exactly one input transition and exactly one output transition. A marked graph with sequential structure is called a sequential Marked Graph (SMG). The subclass of Petri nets for modeling a workflow agent is a SMG augmented with a set of terminal input places and terminal output places. We call this subclass of Petri nets augmented sequential location-aware Marked Graph (ASLMG). In this paper, the workflow model for a workflow agent is described by a timed augmented sequential location-aware Marked Graph (TASLMG). Formally, the Petri net models for workflow agents and resource agents are defined as follows.

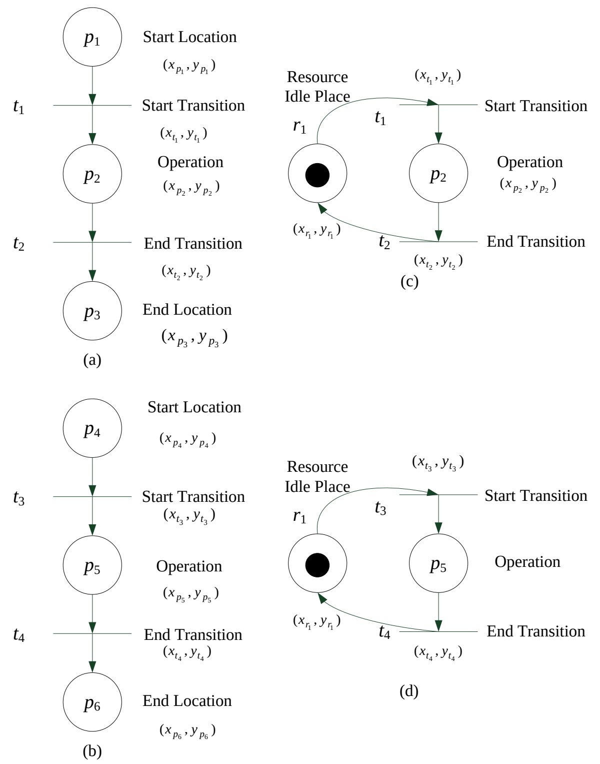

Figure 6. LTPN models

Definition 4.1: The model of workflow agent n, where $w_n \in \boldsymbol{WA}$, is a TASLMG $W_n = (P_n, T_n, F_n, L_n, m_{n0}, \mu_n)$. As each transition represents a distinct operation in a construction project, we have $T_j \cap T_k = \Phi$ for $j \neq k$.

Definition 4.2: LTPN $A_r^k = (P_r^k, T_r^k, F_r^k, L_r^k, m_{r0}^k, \mu_r^k)$ denotes the $k-th$ activity of resource agent r, where $r \in \boldsymbol{RA}$. The initial marking m_r^k is determined by the number of resources allocated to the $k-th$ activity. There is no common transition between A_r^k and $A_r^{k'}$ for $k \neq k'$.

Two examples of Petri net models for workflow agents are illustrated in Fig. 6(a) and (b). A resource agent may be able to perform several activities in the workflows. Fig. 6(c) and (d) shows two Petri net models for two activities of a resource agent.

For location-aware workflows, the processing time (firing time) for the execution of operations (transitions) depends on their location. The workflow scheduling problem needs to be formulated and solved dynamically based on real geographic information system (GIS) or database. The Google Distance Matrix API is a service that provides travel distance and time for a matrix of origins and destinations. The information returned is based on the recommended route between start and end points, as calculated by the Google Maps API, and consists of rows containing duration and distance values for each pair. In this paper, we apply the Google Distance Matrix API to find the processing time (firing time) for transitions in our LTPN models. In other words, the firing time $\mu(t)$ of transition $t \in T$ is calculated by invoking the Google Distance Matrix API according to the location of its input place and location of its output place.

B. Step (2): Scheduling Problem Formulation Based on Extraction of Parameters from Agent Models

The scheduling problem for workflow W_n is to find an allocation of resource capacities over the scheduling horizon that minimizes the total production costs while satisfying all production constraints. Let O denote the number of order agents. Let N denote the number of workflow agents in the system. That is, $\mathrm{N} = |\boldsymbol{WA}|$ and $\mathrm{O} = |\boldsymbol{OA}|$. Let K_n denote the number of different resource activities involved in W_n. The k-th resource activity in W_n is represented by A_r^k, $k \in \{1, 2, \ldots, \mathrm{K}_n\}$. Suppose the k-th resource activity in W_n is performed by resource agent r_k. Then the processing time π_{nk} of the k-th resource activity A_r^k in W_n is $\pi_{nk} = \mu_r^k(t_s^k) + \mu_r^k(t_e^k)$, where t_s^k and t_e^k denote the starting and ending transitions of the k-th activity of resource agent a_r.

Let T denote the total number of time periods. Each $t \in \{1, 2, 3, \ldots, T\}$ represents a time period index. Let C_{rt} denote the capacity of resource r at time period t, where $C_{rt} = m_{r0}^k(r)$. Let d_n denote the due date of workflow agent w_n. Note that the due date d_n for workflow agent w_n is set by its downstream workflow agents in the negotiation processes. Let v_{okt} denote the number of parts of order o loaded onto the corresponding resource r_k for processing the k-th resource activity in W_n during time period t, where $v_{okt} \geq 0$ and $v_{okt} \in Z^+$, the set of non-negative integers.

Let y_{ot} be the number of parts of order o in workflow W_n finished during time period t; i.e.,

Let h_{okt} be the number of parts of order o at the input buffer of the k-th resource activity in W_n at the beginning of period t, where $h_{okt} \geq 0$ and $h_{okt} \in Z^+$, the set of non-negative integers.

We define the earliness/tardiness penalty coefficient ω_{ot} for each product of workflow W_n completed at time t as

$$\omega_{ot} = \begin{cases} E_n(d_n - t), t \leq d_n \\ L_n(t - d_t), t > d_n \end{cases}$$

Mathematically, it is formulated as

$$(SP_n) \qquad \min \sum_{o=1}^{O} \sum_{t=1}^{T} (\omega_{ot} y_{ot})$$

s.t.

$$\sum_{o=1}^{O} \sum_{\tau=t-\pi_{nk}+1}^{t} v_{ok\tau} \leq C_{r_k t} \qquad \forall k \in \{1, 2, \ldots, \mathrm{K}_n\}$$

$$y_{ot} = v_{oK_n(t-\pi_{nK_n})}, \forall o, \forall t$$

$$h_{o11} = Q$$

$$h_{o1(t+1)} = h_{o1t} - v_{o1t}$$

$$h_{ok(t+1)} = h_{okt} - v_{okt} + v_{o(k-1)(t-\pi_{n(k-1)})} \forall k \in \{2, 3, \ldots, \mathrm{K}_n\}$$

$$h_{o(K_n+1)(t+1)} = h_{o(K_n+1)(t+1)} + v_{oK_n(t-\pi_{nk})}$$

In our scheduling system, we apply a subgradient based algorithm to solve the project scheduling problem.

V. IMPLEMENTATION

We have developed a multi-agent location-aware workflow scheduling system based on JADE, a middleware that facilitates the development of multi-agent systems, to realize our methodology. Messages exchanged by JADE agents have a format specified by the ACL language defined by the FIPA international standard for agent interoperability. To apply the contract net protocol, a manager must be able to search for the services provided by the other bidders. Each time an agent is added to the system, its services are published and discovered through the DF agent in JADE. In our scheduling system, order agents, workflow agents and resource agents are accompanied with proper graphical user interface (GUI) for users to input the required data. Optimization agents, which are invoked by workflow agents, have no GUI as they work behind the scenes.

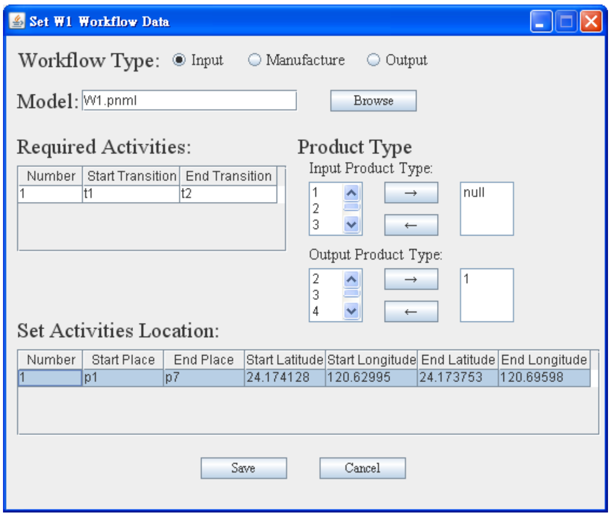

Figure 7. GUI for setting the properties of a workflow agent

To specify the location of a workflow, we have implemented a GUI to set the latitude and longitude of the start location and end location of an activity in a construction project. Fig. 7 illustrates the GUI for setting the parameters of a workflow agent. Similarly, we have implemented a GUI to set the latitude and longitude of the start location and end location of a resource agent. Fig. 8 illustrates the GUI for setting the parameters of a resource agent. Fig. 9 illustrates the graphical user interface (GUI) for setting construction order requirements. The output of our scheduling software includes the schedules for executing each workflow and the schedules for performing the operations of workflows by each resource agents.

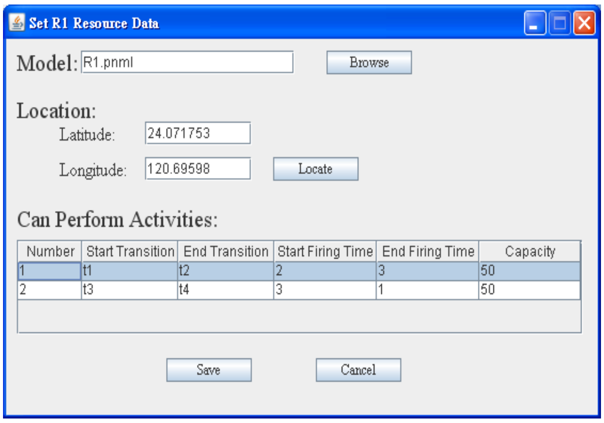

Figure 8. GUI to set the properties of a resource agent

Figure 9. GUI for setting order requirements

Consider an application scenario with three workflow agents (W_1 through W_3) and three resource agents (R_1 through R_3) in a construction supply chain. Table I shows the three workflows in the system. Each workflow represents a process required for manufacturing components or products required for the construction project or execution of a construction task. Suppose a construction order is received. Table II shows the initial location of resource agent. Table III shows the requirements of the construction order. Table IV illustrates the schedule for workflow agents to handle Order 1. It indicates that the due date of Order 1 can be met as the required quantity can be finished at 17:30 on 2014/6/24. Table V shows the schedule for resource agents.

TABLE I. PROPERTIES OF WORKFLOW AGENTS

Workflow ID	Input(s)	Output	Start Location	End Location
W1	Null	1	(24.162188,120.69995)	(24.173753, 120.69598)
W2	1	2	(24.173753, 120.69598)	(24.173753, 120.69598)
W3	2	3	(24.173753,120.69598)	(24.081582, 120.68125)

TABLE II. INITIAL LOCATION OF RESOURCE AGENTS

Resource	Initial Location
R1	(24.155623,120.69421)
R2	(24.173753,120.69598)
R3	(24.176248,120.67629)

TABLE III. ORDER REQUIREMENTS

Order ID	Due date	Product type	Quantity	Earliness Cost	Lateness Cost
1	2014/6/24-17:30	9	100	10	20

TABLE IV. ORDER REQUIREMENTS

Workflow	Start time	End time	Quantity
W1	2014/6/24-14:4	2014/6/24-14:34	100
W2	2014/6/24-15:10	2014/6/24-15:50	50
W2	2014/6/24-15:50	2014/6/24-16:30	50
W3	2014/6/24-16:40	2014/6/24-17:30	100

TABLE V. SCHEDULE FOR RESOURCES

Resource	Start time	End time	Quantity
R1	2014/6/24-14:4	2014/6/24-14:34	100
R2	2014/6/24-15:10	2014/6/24-15:50	50
R2	2014/6/24-15:50	2014/6/24-16:30	50
R3	2014/6/24-16:40	2014/6/24-17:30	100

VI. CONCLUSION

The workflows in a construction project are dynamic and cross organizational boundary. More importantly, location information plays an important role in scheduling the workflow activities and resources that move materials, parts or components from one partner to the next in a construction supply chain. Although workflow management problems have been extensively studied for decades, location aspect of workflows has not been considered in existing literature. In this paper, we study how to exploit recent advancements in multi-agent systems (MAS), information technology and geographic information system (GIS) to reduce cost and time in the development of location-aware workflow scheduling systems based on a sustainable architecture. The location-aware workflow scheduling system aims to find the schedule of resources and activities based on the location information of the entities in the system. We propose a methodology that includes modeling of location-aware workflows based on formal workflow models, develop a technique to transform workflow models to formulate and solve project scheduling problem. We propose a framework to implement a project scheduling system for construction supply chains.

ACKNOWLEDGMENT

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REFERENCES

[1] X. Jiang, N. Y. Chen, J. I. Hong, K. Wang, L. Takayama, and J. A. Landay, "Siren: Context-aware computing for firefighting," in: *Proc. 2nd Int. Conf. on Pervasive Computing, PERVASIVE'04*, Springer, 2004, pp. 87-105.

[2] R. Yus, E. Mena, S. Ilarri, and A. Illarramendi. SHERLOCK: Semantic management of location-based, services in wireless environments, pervasive and mobile computing. [Online]. Available: http://dx.doi.org/10.1016/j.pmcj.2013.07.018

[3] T. Murata, "Petri nets: Properties, analysis and applications," in *Proc. the IEEE*, vol. 77, no. 4, 1989, pp. 541-580.

[4] M. E. Georgy, "Evolutionary resource scheduler for linear projects," *Automation in Construction*, vol. 17, no. 5, pp. 573-583, July 2008.

[5] D. W. Johnston, "Linear scheduling method for highway construction," *Journal of the Construction Division*, vol. 107, no. 2, pp. 247-261, June 1981.

[6] R. B. Harris and P. G. Ioannou, "Scheduling projects with repeating activities," *Journal of Construction Engineering and Management, ASCE*, vol. 124, no. 4, pp. 269-278, July-August 1998.

[7] R. A. Yamín and D. J. Harmelink, "Comparison of linear scheduling model (LSM) and critical path method (CPM)," *Journal of Construction Engineering and Management*, vol. 127, no. 5, pp. 374-381, 2001.

[8] R. M. Reda, "RPM: Repetitive project modeling," *Journal of Construction Engineering and Management*, vol. 116, pp. 2, pp. 316-330, 1990.

[9] D. J. Harmelink, "Linear scheduling model: Float characteristics," *Journal of Construction Engineering and Management*, vol. 127, no. 4, pp. 255-260, 2001.

[10] T. W. Liao, P. J. Egbelu, B. R. Sarker, and S. S. Leu, "Metaheuristics for project and construction management-A state-of-the-art review," *Automation in Construction*, vol. 20, no. 5, pp. 491-505, August 2011.

[11] H. Li and P. Love, "Using improved genetic algorithms to facilitate time-cost optimization," *Journal of Construction Engineering and Management*, vol. 123, no. 3, pp. 233-237, 1997.

[12] B. C. Que, "Incorporating practicability into genetic algorithm-based time-cost optimization," *Journal of Construction Engineering and Management*, vol. 128, no. 2, pp. 139-143, 2002.

[13] H. Ke and B. Liu, "Project scheduling problem with stochastic activity duration times," *Applied Mathematics and Computation*, vol. 168, pp. 342-353, 2005.

[14] C. K. Chang, M. J. Christensen, and T. Zhang, "Genetic algorithms for project management," *Annals of Software Engineering*, vol. 11, pp. 107-139, 2001.

[15] Y. S. Dai, M. Xie, K. L. Poh, and B. Yang, "Optimal testing-resource allocation with genetic algorithm for modular software systems," *The Journal of Systems and Software*, vol. 66, pp. 47-55, 2003.

[16] P. Y. Yin and J. Y. Wang, "An colony optimization for the nonlinear resource allocation problem," *Applied Mathematics and Computation*, vol. 174, pp. 1438-1453, 2006.

[17] Z. Ren and C. J. Anumba, "Learning in multi-agent systems: A case study of construction claims negotiation," *Advanced Engineering Informatics*, vol. 16, pp. 265-275, 2002.

[18] X. L. Xue, X. D. Li, Q. P. Shen, and Y. W. Wang, "An agent-based framework for supply chain coordination in construction," *Automation in Construction*, vol. 14, no. 3, pp. 413-430, 2005.

[19] F. Peña-Mora and C. Y. Wang, "Computer-supported collaborative negotiation methodology," *Journal of Computing in Civil Engineering*, vol. 12, no. 2, pp. 64-81, 1998.

[20] J. Son and M. J. Skibniewski, "Multiheuristic approach for resource leveling problem in construction engineering: Hybrid approach," *Journal of Construction Engineering and Management*, vol. 125, no. 1, pp. 23-31, 1999.

[21] S. S. Leu, C. H. Yang, and J. C. Huang, "Resource leveling in construction by genetic algorithm-based optimization and its decision support system application," *Automation in Construction*, vol. 10, pp. 27-41, 2000.

[22] T. Hegazy, "Optimization of resource allocation and leveling using genetic algorithms," *Journal of Construction Engineering and Management*, vol. 125, no. 3, pp. 167-175, 1999.

[23] M. Wooldridge, *An Introduction to MultiAgent Systems*, New York: John Wiley & Sons Ltd, 2002.

[24] M. Wooldridge and N. R. Jennings, "Intelligent agents: Theory and practice," *The Knowledge Engineering Review*, vol. 10, no. 2, pp. 115-152, 1995.

[25] W. M. P. van der Aalst, "The application of petri nets to workflow management," *J. Circuit. Syst. Comput.*, vol. 8, no. 1, pp. 21-66, 1998.

[26] W. M. P. van der Aalst and A. Kumar, "A reference model for team-enabled workflow management systems," *Data & Knowledge Engineering*, vol. 38, no. 3, pp. 335-363, September 2001.

[27] M. Weske, W. M. P. van der Aalst, and H. M. W. Verbeek, "Advances in business process management," *Data & Knowledge Engineering*, vol. 50, no. 1, pp. 1-8, July 2004.

[28] R. G. Smith, "The contract net protocol: High-level communication and control in a distributed problem solver," *IEEE Transactions on Computers*, vol. 29, pp. 1104-1113, 1980.

[29] D. C. McFarlane and S. Bussmann, "Developments in holo-nic production planning and control," *International Journal of Production Planning and Control*, vol. 11, no. 6, pp. 522-536, 2000.

[30] H. V. D. Parunak, "Manufacturing experiences with the contract net," in *Distributed Artificial Intelligence*, M. Huhns Ed. London: Pitman, 1987, pp. 285-310.

[31] C. Ramos, "A holonic approach for task scheduling in manufacturing systems," in *Proc. 1996 IEEE International Conference on Robotics and Automation*, 1996, pp. 2511-2516.

[32] R. W. Brennan and D. H. Norrie, "Evaluating the performance of reactive control architectures for manufacturing production control," *Computers in Industry*, vol. 46, pp. 235-245, 2001.

[33] T. Neligwa and M. Fletcher, "An HMS operational model," in *Agent-Based Manufacturing: Advances in the Holonic Approach*, S. M. Deen Ed. Berlin: Springer-Verlag, 2003, pp. 163-191.

[34] M. Weber and E. Kindler. (2002). The Petri Net Markup Language. [Online]. Available: http://www2.informatik.hu-berlin.de/top/pnml/download/about/PNML_LNCS.pdf

[35] J. Billington, S. Christensen, K. V. Hee, E. Kindler, O. Kummer, L. Petrucci, R. Post, C. Stehno, and M. Weber, "The petri net markup language: Concepts, technology, and tools," *Lecture Notes in Computer Science*, vol. 2679, pp. 483-505, 2003.

[36] R. Vrijhoef and L. Koskela, "The four roles of supply chain management in construction," *European Journal of Purchasing & Supply Management*, vol. 6, pp. 169-178, 2000.

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