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An auction based negotiation protocol for resource allocation in customized housing construction

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Abstract

Scheduling has long been a challenge to housing construction industry. It is critical to find a dynamic resource allocation mechanism that can fit into the intrinsically distributed subcontracting project and react to highly dynamic real-time event from construction site. An agent based scheduling mechanism is proposed at operation level to address the distributed decision making structure in housing construction context. An auction based negotiation protocol is presented to facilitate coordination among distributed scheduling agents. The proposed mechanism has been evaluated favorably in terms of load balancing and resource utilization under dynamically changing environment.

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Keywords: Negotiation; Resource allocation; Customization; Construction; Scheduling

1. Introduction

Scheduling considers the problem of allocating scarce resources to activities over time. It plays an important role in delivering projects on time and within budget [1-2]. However, scheduling has long been a challenge to contractors in housing construction industry because of the intrinsically distributed subcontracting project delivery practice and the highly dynamic working environment. Moreover, with the emergent customer requirements on customization, contractors are confronted with larger variation in tasks, higher dynamics in tasks arrival, tighter project delivery time window, under which, traditional centralized scheduling approaches are no longer efficient [4]. Traditional scheduling techniques are applicable to centralized and deterministic setting. Deterministic approaches lack the ability to react to real-time events, which happened quite often in construction projects. Centralized approach cannot respond to system dynamics and requires prior knowledge about the problem instance, which is difficult to obtain in highly distributed construction project delivery systems. Basically, the object is to build the scheduling approaches for subcontractors in housing construction context to meet the following challenges:

Distributed: Both information and decision making are distributed in construction project context. It is difficult to perceive global information or allowing any entity to make centralized decisions for others because subcontractors are self-interested decision making entities. However, activities that compete for scarce resources are interdependent among subcontractors, requiring the self-interested parties to coordinate, negotiate and cooperate to obtain globally satisfactory schedules. It is demanding to have a scheduling mechanism that enables distributed decision making;

Flexible: The scheduling network for a customized housing construction project changes from time to time. Subcontractors enter for executing required activities when the commitment are set by the customers and leaves after completion. Their connections with preceding, concurrent or succeeding parties are dynamic over time. This not only requires a scheduling mechanism being distributed, but also being

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invulnerable to dynamic changes in the structure of the scheduling problem;

Dynamic: Uncertainties are inevitable and common in construction industry. Processing time for a given activity depends on customer requirements, availability and capability of the resource, needs for reworks etc, which may vary from a fixed rough estimation. In this case, scheduling mechanism should also be able to react to real-time events that are resulted from such uncertainties in a timely manner;

It is desirable to have a scheduling mechanism that take into account the dynamic and distributed nature of the construction scheduling problem as well as temporal dynamics that are likely to happen. The objective of this research is to propose a scheduling mechanism that is able to dynamically allocation activities to scarce resources with the absence of a master scheduler in fully distributed environment.

Agent-based approaches have been studied extensively in manufacturing domain as a promising way to deal with open and dynamic scheduling environment because of its decentralized, autonomous, coordinated, and rational nature [3][6-8]. In this paper, the scheduling problem is considered in the context of customized housing construction. By identifying the similarity and distinctions to manufacturing scheduling problems, an agent-based scheduling approach is proposed at operation level to facilitate decision making for subcontractors in housing construction context.

2. Problem Descriptions

2.1. Scheduling in Customized Housing Construction

A typical construction project adopts subcontracting project delivery practice, which makes the scheduling problem inherently distributed. Construction activities requires wide range of skills (e.g., electrical, plumbing, iron work, HVAC and roofing) that can only be performed by specific skilled labor and tools. Thus, Specialty Contractors (SC) are selected by General Contractor (GC) to complete certain type of activities on the basis of performance specifications set forth by the Owners, Architects and Engineers. Most commonly, the involvement of SCs are established on contractual basis to GC only. There are no contractual agreements among SCs, which is problematic because construction activities are highly interdependent. In general, GC is expected to orchestrate all activities among subcontractors and take up the coordinator role in the scheduling process. However, because of the complexity and domain knowledge intensive nature of construction activities, GC, in practice, cannot make a global decision for all the involved parties. In practice, SCs construct their own schedules based contractual requirements, which indeed makes scheduling decisions in a distributed fashion.

The emergence of customized housing project has brought large job variation into the scheduling concern. Firstly, customer requirements largely determine the difficulty level of an activity, which cannot be predicted beforehand. Secondly, such randomness will likely result in delay in processing an activity. As a consequence, if any postponement is needed for an activity, the execution of succeeding activities has to be rescheduled. Both uncertainties from duration of the activity and arrival of an activity can greatly affect the quality of a predefined schedule under highly dynamic environment. The take-it-for-granted fixed and deterministic settings on the duration of the activities are, in fact, dependent on the requirements of the activity, resource capability, and effectiveness of labors or machines. Such information may not be known at the beginning of the project, rather more reliable information can be obtained as it gets closer to the activity execution.

Housing construction industry is confronted with emerging challenges from ever changing customer requirements, fundamental changes in project delivery practice, and fragmented nature of the industry. Traditional project planning and scheduling techniques oversee the scheduling problem in a centralized and deterministic way, which can no longer meet the requirements from customized housing context. It is imperative to have a scheduling mechanism that takes into consideration the decentralized scheduling problem in highly dynamic environment.

2.2. Problem Formulation

Suppose a resource allocation problem that consists of n tasks that is restricted by precedence requirements. Each task i is associated with a type k that maps to the type of resources needed to execute the activity. Any task i will be given an earliest starting time e_i and specified due date dd_i. There are K sets of resource pool, containing at most R_k type k operators. A capable operator in resource pool K is denoted by kw. Each operator kw for a given task i will need $d_{i,kw}$ days of execution. The decision variable for the resource allocation problem is the starting time s_i of task i assigned to operator kw in resource pool K. The objective is to meet time window requirements.

The aforementioned problem is derived from a general Resource Constrained Project Scheduling Problem (RCPSP), with resource dependent processing time of activities. A general RCPSP is an NP-hard problem [1] that are difficult to solve even with small