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A Multi-Agent System based simulation approach for planning procurement operations and scheduling with multiple cross-docks

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ABSTRACT

Reducing food wastage during procurement, collection and storage remain understudied in the context of the developing world that faces unique challenges not seen in the developed world. In order to achieve this objective, a simulation-based framework is needed for evaluation of decision-making policies in procurement context. In this research we propose a Multi-Agent System framework, specifically considering the Indian scenario of paddy procurement operations. We formally define procurement, allocation, milling and scheduling agents under this context and explicitly state the interaction protocols and related algorithms. Procurement agents solve the problem of allocation and maximum coverage to strategically determine their locations. An Improvised Contract Net Protocol is implemented by allocation agents to either reorganize excess procurement quantities among procurement agents or tag to milling agents who implicitly engender disturbance in the system. Scheduling agents solve a Vehicle Routing Problem with Multiple Cross-Docks to determine near optimal routing using a Particle Swarm Optimization Approach. All these agents are entities of a homogeneous system and collectively co-operate and communicate on behalf of a single superior entity. Simulations were performed to identify results such as the percentage of procurement covered, the number of tasks generated, the number of tasks not assigned to any agent.

1. Introduction

The issue of food wastage is very crucial for a country's efforts in improving food security and achieving self-sufficiency. Developing nations of the globalized world have realized this cardinal goal. In a country like India with a population of 1.2 billion, the current figure of food wastage due to the lack of proper handling, transportation, and infrastructure is as high as 45% (post-harvest to distribution) (Parfitt, Barthel, & Macnaughton, 2010). Reducing food wastage during procurement, collection and storage remain understudied in the context of the developing world that faces unique challenges not seen in the developed world. Research in this direction not only reduces the food wastage but will also aid the procurement strategy and price support operations. It can further improve the buffer stock maintenance, optimal level utilization of storage capacity and efficient movement of food grains from the storage facility to demand areas. Close analysis of procurement, collection and storage system in line with demand will determine the long-term requirement of storage facilities, procurement strategies, rail-road network integration and improvement and production and buffer stock requirements.

Procurement of essential food grains generally occurs for a short period of time in a year during which procured food grains are kept very close to the rail -road transportation network node. During this time, uncertainty and availability of rail rakes, trucks, and storage facility lead to the open space storage of food grains causing major wastage. Research related to food grain transportation, procurement and distribution are very limited in supply chain context and a few related works are mentioned here. (Farahani, Asgari, Hojabri, & Jaafari, 2009) considered the minimization of transportation and storage costs to determine the quantity of wheat to be transported to the warehouses in a case of wheat production in Iran. On the other hand, a lot of research has been conducted in production research where products are transported from the manufacturing units to warehouses. (Ng & Lam, 2014) developed a functional clustering approach to solve the supply network optimization problem. Thus, the motivation in considering the

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procurement scenario of the food grain supply chain in the Indian context is evident.

Evaluation of the dynamic policy related changes so as to aid the decision-making process might demand a simulation-based approach. However a traditional simulation-based approach without modeling the negotiations involved would not suffice and for this purpose, we need a framework that involves agent-based technology. The application of intelligent Multi-Agent Systems (MAS) to such a problem can be used as a flexible and reconfigurable approach to model the scenario. MAS have the capabilities to solve problems that might be too large for a centralized single agent; to provide solutions to inherently distributed problems, to offer conceptual clarity and simplicity of design and to handle uncertain data knowledge (Green, Hurst, Nangle, & Cunningham, 1997). One such similar application of the covering problem in MAS literature is coordinating the Mobile Sensor Team (MST). Multiple entities in such systems are considered to be a particular agent types that act autonomously to pursue their desired objective. Additionally, interactions and negotiations through mechanisms allow these agents to gain further information of a partially known system and seek a wider objective of a type of agents (Allard & Shekh, 2012). It is based on these mechanisms upon which the ability of the agents to achieve near optimal solution (achieve the objective) depends on. Therefore, the key to achieving system optimization in such MAS is proper interaction and negotiation protocols. Though the idea of MAS has been applied elegantly to several areas such as computer games, transportation logistics, defense and mobile sensor team, the concept of MAS framework to the best of our knowledge is not established in the context of procurement for food supply chains. However in this paper, we develop a MAS framework that mimics the current scenario of procurement operations in India that can facilitate further investigations on policy changes. Thus, the contribution of the paper to develop a MAS framework can be justified in this context. In this paper, we also propose a novel Vehicle Routing Problem with Multiple Cross Docks (VRPMCD) formulation for multiple items under time and capacity constraints based on which scheduling agents execute the orders. Complete description of the problem is under Section 4. On the technical front, the contributions are twofold. The proposed framework is novel for the scenario of procurement operations and the formulation of a VRPMCD for the scheduling agents is not tackled in literature. We specifically consider the procurement operations under the Decentralized Procurement System (DPS) of procurement of paddy accredited and monitored by respective state agencies and the Food Corporation of India (FCI). Furthermore, in the context of food procurement, the key contribution is that procurement operations can be simulated well ahead of time. This allows us to determine the various decision variables including locations as discussed in our approach. Lack of efficient utilization of resources and effective policies is cited as one of the main reasons for food wastage in developing nations (BRIC) (Parfitt et al., 2010). Our approach is aimed to overcome both these factors through an effective MAS framework. Since we try to mimic the exact scenario of procurement, proper utilization of infrastructure and effective management of associated technical resources with good policies can be implemented and are the main implications of such a framework. Since, there is no such MAS framework, comparisons are not relevant with any existing benchmark problems.

The remainder of the paper is organized as follows. The following section briefly highlights some relevant literature pertaining to MAS and their interaction protocols. In Section 3 we describe the procurement scenario and provide a pictorial description of the MAS framework with explicit details of which are discussed in Section 4. Section 5 highlights the experimental setup under which the simulations are carried out and insights into results are provided. Finally, conclusions are provided in Section 6.

2. Literature review

The literature mentioned here briefly discusses the literature pertaining to MAS and VRPMCD. Traditionally, research-involving MAS is carried out as Distributed Artificial Intelligence (DAI), and can be bifurcated broadly into Distributed Problem Solving (DPS) and Multi-Agent Systems (MAS) (Bond & Gasser, 1988). The most primary and elemental term in MAS, agent – has its origins from the actor model of Hewitt (1977). It presented an approach for problem – solving based on communicating knowledge among experts. The term agent has gained significant importance and has gained the attention of researchers especially in the fields of agent theory, agent architectures, and agent languages. (Wooldridge & Jennings, 1995), listed the four main capabilities of agents in MAS. They are - they act autonomously, independent decision making for satisfying objectives, environment perception – respond to changes and that they are proactive. In opposition to the standard definition of agent, a network of agents namely MAS are capable of problem solving that is not within the reach of discrete agents (Jennings, 2000). These MAS are either homogenous or heterogeneous and may include agents whose negotiations are competitive or co-operative, that allows them to perform a set of tasks allocated to them to pursue their set of objectives (Lesser, 1999). As discussed earlier coordination is the key to any MAS, to decide the agent's own actions in view of other agents capabilities and activities so as to achieve the goal (Durfee, 2001). However to realize this, these agents must not only negotiate but also interact and exchange information, i.e. they need to communicate. Thus, a means of negotiation and communication through various protocols and languages are necessary to understand and collectively work together (Bond & Gasser, 1988).

One of the basic protocols in communication is the Contract Net Protocol (CNP) put forward by Smith (1980). The well-known CNP is used for announcing the tasks to other agents within the system and thereby requesting bids for the same. However some shortcomings of this protocol include not being able to resolve conflicts, no information on refused bids, no prioritization for time critical tasks, and is communication intensive (Jennings, Sycara, & Wooldridge, 1998). Such shortcomings have been mitigated by proposing extensions like CNP based on marginal cost calculations (Sandholm, 1993). Several real-world applications of the agent-based technology have evolved and have a profound effect on both industrial and commercial sector. One such area of agent-based research is the allocation and coverage problem where entities have to be strategically located in a geographical area so that the region is under surveillance of the entities. Research in this direction has found applications in wireless sensor networks (Habib, 2007), emergency vehicle dispatch (Ibri, Nourelfath, & Drias, 2012), mobile sensing teams (Zivan, Yedidsion, Okamoto, Glinton, & Sycara, 2015) and military applications (Amstutz, Correll, & Martinoli, 2008). To the best of our knowledge there is no literature on application in procurement operations of such an allocation and covering problem. Formulating a distributed constraint optimization problem (DCOP) in an attempt to achieve global near optimum for all the agents has been identified as a solution approach (Modi, Shen, Tambe, & Yokoo, 2003; Yokoo, Durfee, Ishida, & Kuwabara, 1998). A well-known DCOP algorithm with fast convergence is the Maximum Gain Message algorithm (MGM) (Zivan et al., 2015). MGM algorithm is based on the Distributed Breakout Algorithm (DBA) developed by Yokoo and Hirayama (1996), inspired by the breakout algorithm for solving centralized constraint satisfac-