A MULTI-AGENT-BASED APPROACH TO DYNAMIC SCHEDULING OF MACHINES AND AUTOMATED GUIDED VEHICLES (AGV) IN MANUFACTURING SYSTEMS BY CONSIDERING AGV BREAKDOWNS

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Abstract

In a competitive business environment, producing goods on time plays a very important role. In addition to regular control complexities in manufacturing environments, some unforeseen technical problems may affect the efficiency of production. The breakdown of automated guided vehicles (AGV) during manufacturing is one of these problems. This problem generally requires an instantaneous solution while the system is operating. However, traditional production control systems and algorithms handle this kind of problem centrally and usually are not able to provide effective solutions promptly. One possibility is to use a multi-agent-based scheduling approach for AGVs and machines within a manufacturing system that takes into consideration AGV breakdowns. After implementation, this approach is designed to work in a real-time manufacturing environment and feasible schedules should emerge from negotiation/bidding mechanisms between agents.

Introduction

Producing goods on time plays a very important role in manufacturing control and planning. Production plans and schedules are generally interrupted with unexpected events around or within the system. These problems may affect the efficiency of production planning or they may collapse all the plans of operations. The breakdown of automated guided vehicles (AGV) in flexible manufacturing systems is one of those problems. AGV systems are industrial transportation systems used in various industrial contexts: container terminals, parts transportation in heavy industry, and manufacturing systems [1-3]. They have considerable functionality in manufacturing systems and container terminals may be the source of unexpected events within a manufacturing or logistics system.

The operational decisions of AGVs especially attracted researchers to design and implement cost-effective operating decisions. However, the complexity of the problem has led the researchers to use distributed methods other than central optimization approaches. Distributed artificial intelligence, such as multi-agent-based systems, can allow for effective management of dynamic manufacturing operations. As is expected from a fairly young area of research, there is not yet universal consensus on the definition of an agent [4]. However, the Wooldridge and Jennings' definition is increasingly adopted in this field: "An agent is a computer system that is situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives" [5]. An agent is a component that can exhibit reasoning behavior under both proactive (goal-directed) and reactive (event-driven) stimuli. When an agent is instantiated, it will wait until it is given a goal to achieve or experiences an event that requires a response [6].

Some of the authors of this study have previously addressed a multi-agent-based simultaneous AGV and machine scheduling approximation and tested it on test-bed problems [7]. Multi-agent-based approximation has proven its success in dynamic and volatile business environments. However, AGV breakdown occurrences were not considered in previous studies. The AGVs were assumed to be operational without breaking down throughout the entire manufacturing process. In this current study, the breakdowns of AGVs were considered to extend the scope of the previous studies. The intention of this study is to get closer to real manufacturing environments.

Literature Review

Previous studies on AGV control have a wide scope in the literature and range from traffic control on the AGV paths to AGV deadlock prevention [8], [9]. The application areas range from manufacturing floors to container terminals [7], [10]. The solution approximation for AGV control also encompasses a wide research domain, from integer programming to meta-heuristics, and from Petri-net to multi-agent systems [7], [8], [10-13]. However, this current literature review focused on AGV breakdown during real-time manufacturing operations, of which few studies were found. Of those reviewed, AGV failures on automated transportation systems were neglected. According to Ebben [14], when an AGV breaks down, it may stop other AGVs. There are two options when the AGV breaks down: it can be fixed on the system or removed from the system to the repair section; the choice generally depends on repair time.

Taghaboni-Dutta and Tanchoco [15] noted that routing flexibility allows a quick recovery to breakdowns and other disruptive events, but their study does not examine failures. According to their study, failures can be neglected in AGV systems when the AGV workload is low and failures can be resolved quickly. Another study about AGV control that considered disturbances was by Badr et al. [16]. They presented five steps to clarify disturbance handling during dynamic scheduling: disturbance detection, disturbance analysis, action selecting, action announcement, and schedule repair. Merdan et al. [17] proposed an approximation for conveyor and machine failures in workflow scheduling by using a multi-agent system. They tested dispatching rules in combination with the all re-routing re-scheduling policies under machine and conveyor failures. They then ranked the rules based on their performance results from the simulation.

Design of an AGV Resource Agent during Breakdown

In this current study, an AGV breakdown situation was modeled under a multi-agent-based system approach. The system was designed using the Prometheus methodology that defines a detailed process for specifying, designing, implementing, and testing/debugging agent-oriented software systems. This methodology was developed for specifying and designing agent-oriented software systems, and is considered general purpose in that it is not tied to any specific software platform. Unlike other methods, Prometheus supports the development of intelligent agents, provides start-to-end support, evolved out of practical industrial and pedagogical experience, is used in both industry and academia, and is detailed and complete [4]. Figure 1 presents the phases of the Prometheus design methodology.

System Specification

The agent types are decided and designed through the stages of this design methodology. Here are the agent types in the proposed system: Machine Resource Agent, Machine Scheduler Agents, AGV Resource Agent, AGV Scheduler Agents, and Operation Agent. In the system specification stage of Prometheus, negotiations between agent types, system goals, agent roles in the system, and scenarios are identified. Figure 2 shows the system specification stage of the Prometheus methodology. There are four main roles in the system: AGV management, machine management, system management, and negotiation management.

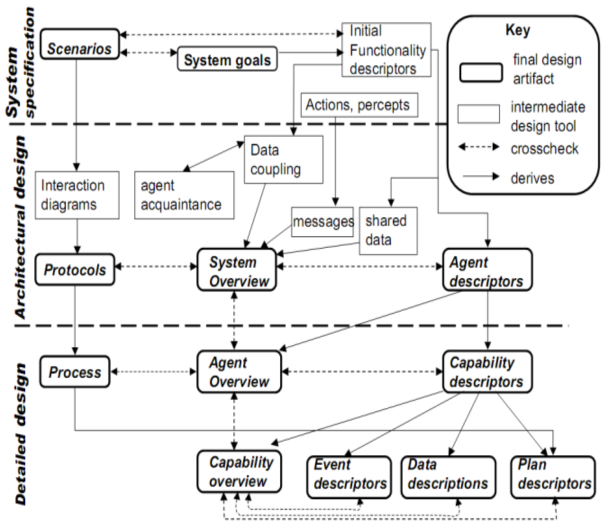

Figure 1. Phases of the Prometheus Methodology [4]

This study focused on the AGV management role in the system specification stage. The ovals in Figure 2 show the goals of the system elements. One of the goals of the AGV management role for the proposed system was “AGV Scheduling after AGV Breakdown” (see Figure 2). The sub-goal is also designed in the system specification stage. Three sub-goals of the “AGV Scheduling after AGV Breakdown” goal are given in Figure 3:

1. AGV that is loaded and has a task in its blackboard.
2. AGV that is free and has a task in its blackboard.
3, AGV that is loaded and has no task in its blackboard.

Architectural Design

The negotiation protocols between agent types were designed in this stage of the Prometheus methodology. A system overview diagram is given in Figure 4. The AGV scheduler agent negotiates with operation agents in order to find real-time operation transportation and processing schedule. Figure 4 also shows an example negotiation protocol between operation agents and scheduler agents. When an operation agent enters into the proposed multi-agent-based system then it calls for proposals for the machine and scheduler agents that are available in the system. When the order agent finds a proper machine agent to be processed, it then calls for a proposal to a scheduler agent to be transported to the machine.

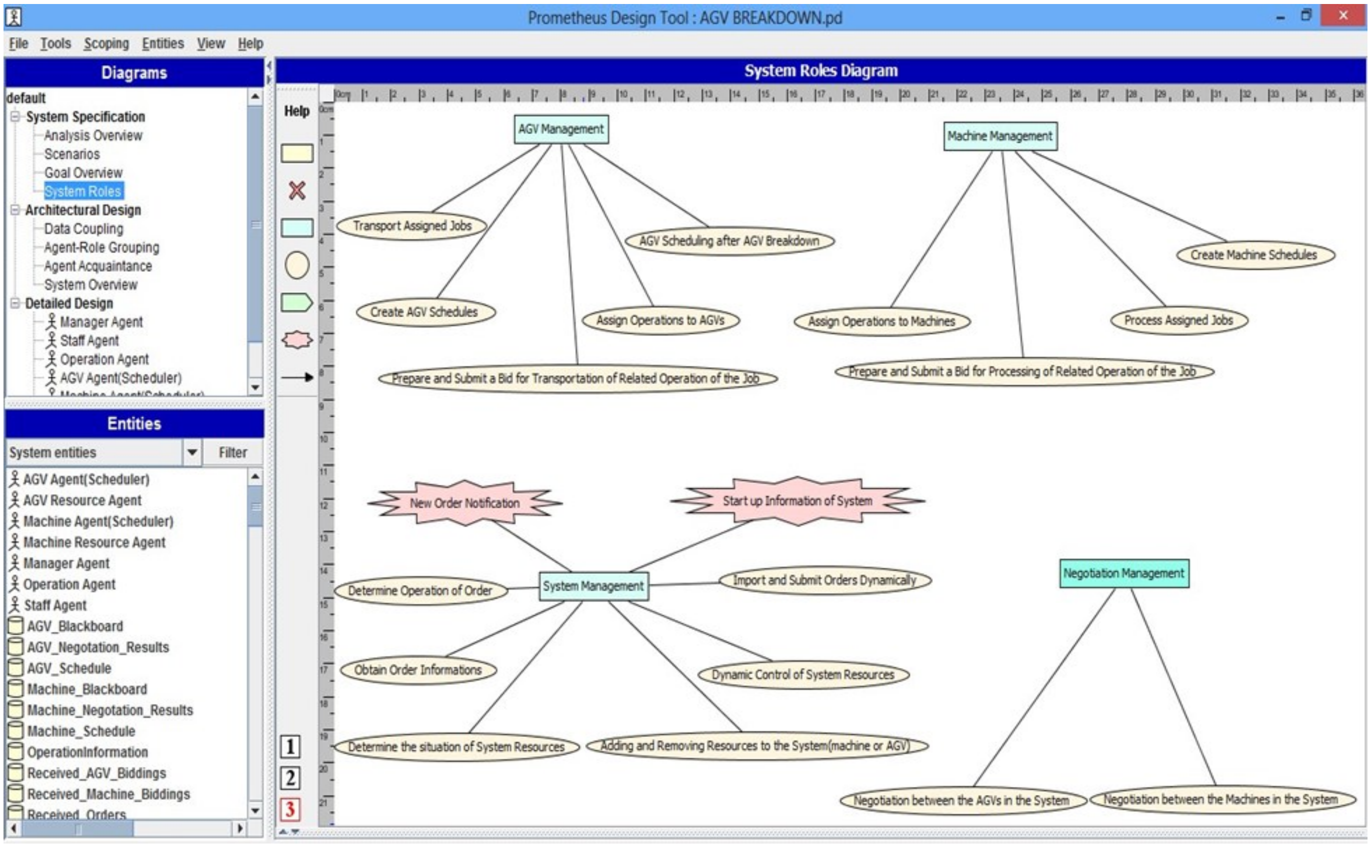

Figure 2. System Roles in PDT

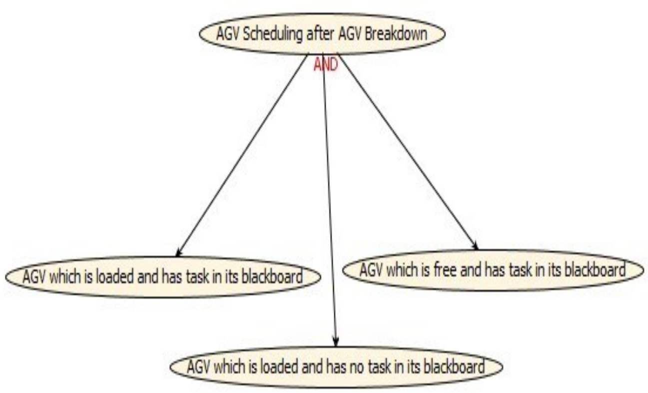

Figure 3. Sub-goals of the "AGV Scheduling after AGV Breakdown" Goal

Detailed Design

In the detailed design stage, the capabilities of the scheduler agent type are defined by the breakdown condition. A resource agent could be in any of the following states in a flexible manufacturing system:

1. Idle and ready
2. Transportation of an operation
3. Deadheading trip (going to take a job from a machine)

While the AGV resource agent is operating, it can break down. The AGV resource agent has an attribute of working status of either "in working condition" or "broken down"; its status changes from "in working condition" to "broken down" when it breaks down. In all three states, the resource agent updates its status attribute. The resource agent sends the breakdown information to the scheduler agent after updating its attribute. Figure 5 shows the detailed design for the resource agent. Figure 6 shows the negotiation protocol of resource and scheduler agents. When the scheduler agent receives the breakdown message, it reasons in one of three ways by controlling the blackboard. Figure 7 shows a detailed design for the scheduler agent. When the scheduler agent takes the breakdown message from the resource agent, it sends the message to the operation agents in its blackboard, which then start a new negotiation with the scheduler agents in order to be transported. Figure 8 shows the standard negotiation protocol between operation and scheduler agents.

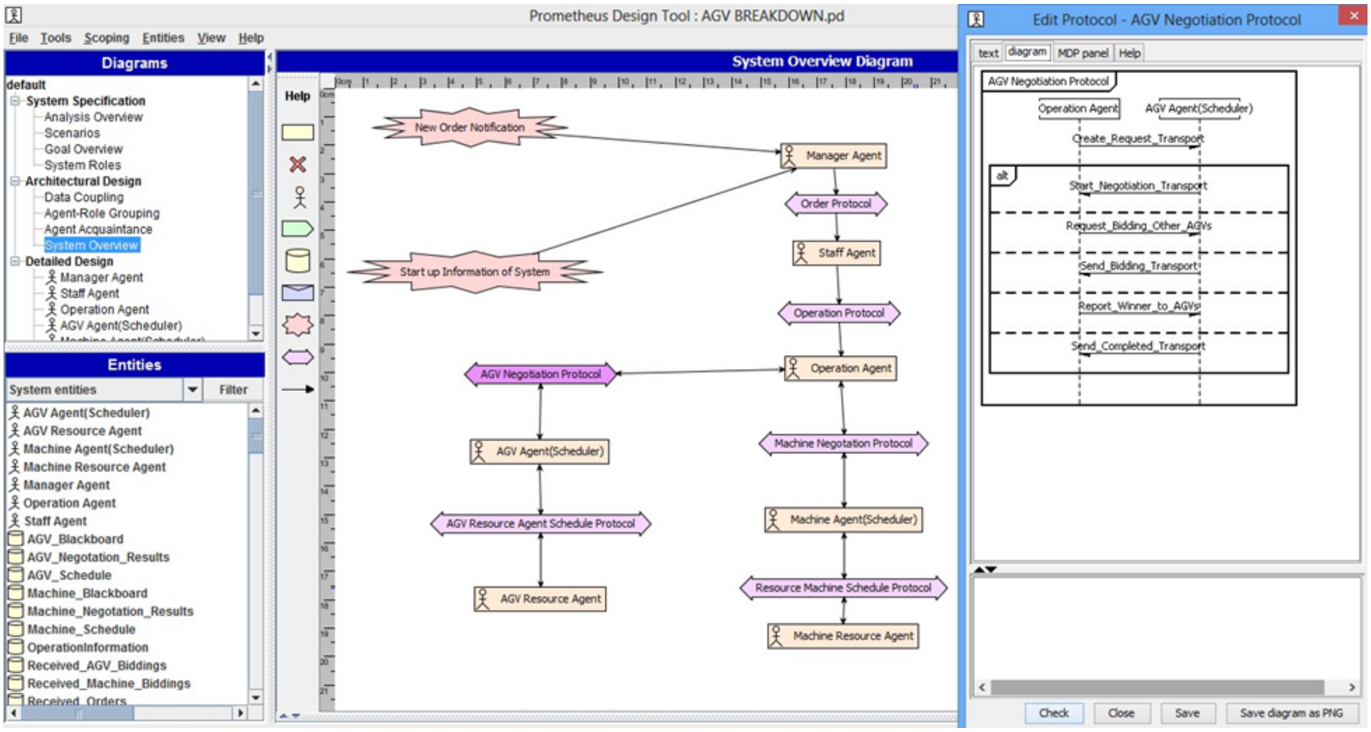

Figure 4. System Overview

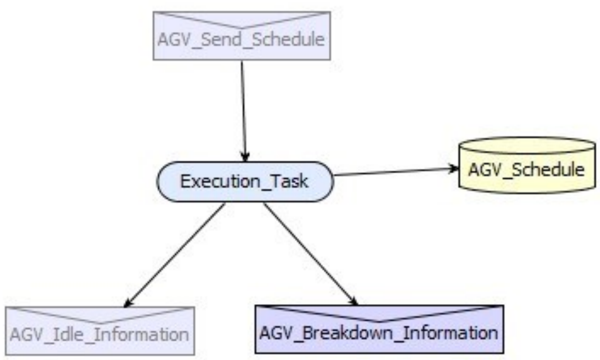

Figure 5. Detailed Design of an AGV Resource Agent

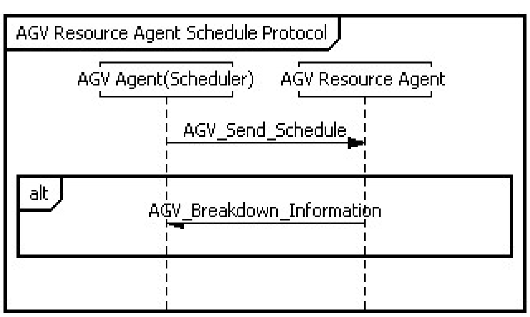

Figure 6. Negotiation Protocol of AGV Resource and AGV Scheduler Agents

Algorithm for AGV Breakdown Conditions

This section details the scheduler agent's decision making. The operation agent informs the scheduler agents when the AGV breaks down. The scheduler agent then assesses the coordination information inside the messages and performs a reward. Scheduler agents consider the proposal of machine operations as "broken down" AGV, according to Equation (1). After the AGV breaks down and the blackboard resets, the current time must be equal to the earliest pickup time of operation i:

$$t = EPT_i, \text{ so } ELT_i = \{t + \Delta t(CL, AGVBDP_i)\} \quad i = 1\ldots n \tag{1}$$

where, ELT_i denotes the earliest loading time of operation i; CL is the current location of the AGV resource agent; $AGVBDP$ is AGV's breakdown point for operation i; t is the current time; Δt(.,.) is the required time between two locations; and, EPT_i is the earliest pickup time of operation i.

Scheduler agents evaluate the proposal according to Equation (2):

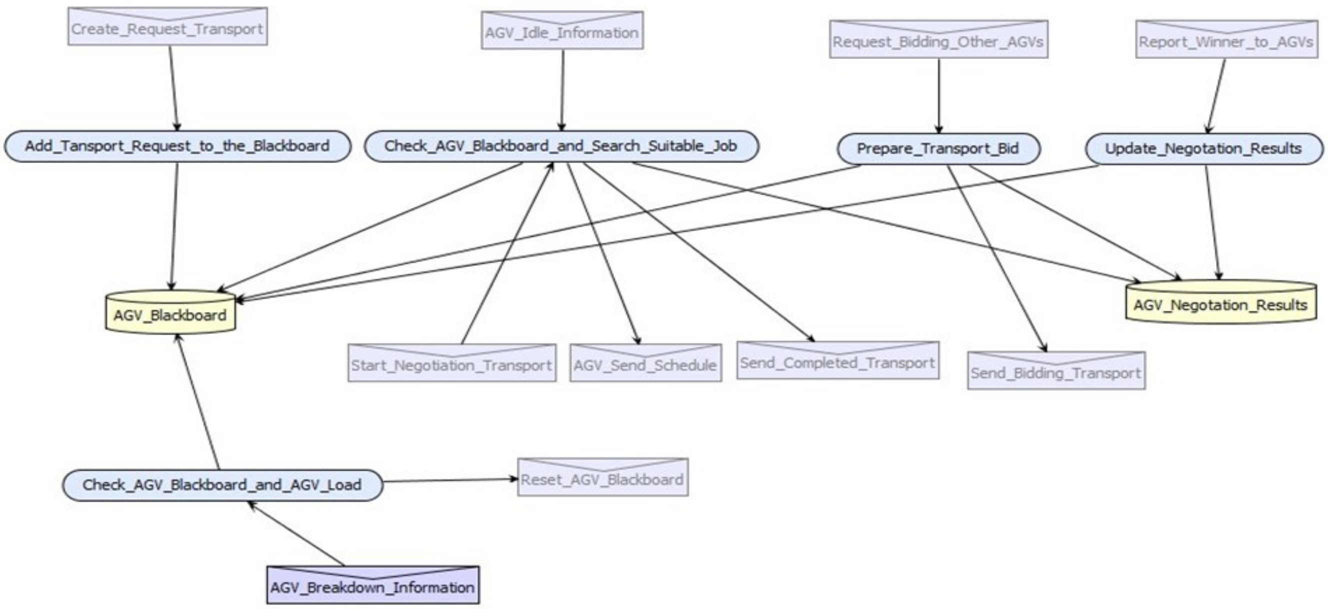

Figure 7. AGV Scheduler Agent with Details

$$ELT_i = \begin{cases} t + \Delta t(CL, PCP_i), & t > EPT_i, \\ t + \max\{\Delta t(CL, PCP_i), (EPT_i - t)\}, & t \le EPT_i, \end{cases}$$

$i = 1 \ldots n$ (2)

where, ELT_i denotes the earliest loading time of operation i; CL is the current location of the AGV resource agent; PCP_i is the pickup point of operation i; t is current time; $\Delta t(.,.)$ is the required time between two locations; and, EPT_i is the earliest pickup time of operation i.

Then, an operation is selected from the AGV blackboard by using Equation (3):

$$ELT_s = \min\{ELT_i\},$$
$i = 1 \ldots n$ (3)

The scheduler agent then proposes a time to the respective operation agents by adding $ELTs$ to the related loaded trip time, as shown in Equation (4):

$$PR = ELT_s + \Delta t(PCP_s, DP_s) \quad (4)$$

After the start of the negotiations, operation agents call to all scheduler agents to submit a proposal. This plan first checks whether an operation has already been rewarded. If there is not a rewarded operation, then it prepares an offer. When preparing a proposal, the scheduler agent finds the operation that has the minimum ELT, using Equations (5) and (6), where EFT and NL denote the earliest free time and the next location of the AGV resource agent, respectively.

$$ELT_i = \begin{cases} EFT + \Delta t(NL, PCP_i), & EFT > EPT \\ EFT + \max\{\Delta t(NL, PCP_i), (EPT_i - EFT)\}, & EFT \le EPT \end{cases}$$

$i = 1 \ldots n$ (5)

$$ELT_s = \min\{ELT_i\},$$
$i = 1 \ldots n$ (6)

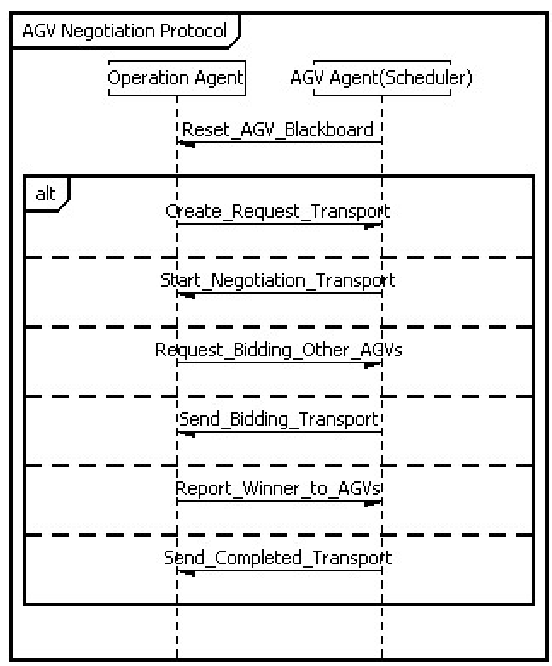

Figure 8. Negotiation of Operation and AGV Scheduler Agents

If the operation in the current negotiation matches the selected operation in the scheduler agent's blackboard belief set, the scheduler agent proposes operations by adding *ELTs* the related loaded trip time, as given by Equation (7):

$$PR=ELT_s + \Delta t(PCP_s, DP_s) \quad (7)$$

Conclusions and Future Research

Resources that are used in flexible manufacturing systems pose unforeseen technical problems in addition to regular control and maintenance complexities. The breakdown of AGVs during real-time manufacturing affects many related schedules of operations and machines. This problem generally requires an instantaneous solution, while the system is operating. The proposed multi-agent-based design was developed in order to solve these complexities during the manufacturing process. The design uses the capabilities of multi -agent systems in order to solve real-time scheduling complexities. Feasible and effective schedules were expected to emerge from negotiation/bidding mechanisms between agents. Future research directions include

- Implementing the proposed design on a multi-agent programming language.
- Finding test-bed studies in order to compare the results of multi-agent systems with other approximations.
- Developing multi-agent-based simulation models in order to test the effectiveness of the proposed model.

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