ORGANIZATION-ORIENTED KNOWLEDGE SYSTEMS FOR CONSTRUCTION E-BUSINESS

E. A. Obonyo
obonyo@ufl.edu
Rinker School of Building Construction, University of Florida, United States

Abstract

A number of construction industry-specific, agent-based applications have been deployed to enhance knowledge systems. These applications are generally speaking Agent-Centered Multi-Agent Systems (ACMAS). Interaction between ACMAS agents is designed around the internal mental state of an agent, the relationship between these states and its overall behavior. Communication in this approach comprises speech acts whose meaning can be described in terms of the mental states of an agent. This interaction protocol makes it difficult for agents implemented using different approaches to communicate. This paper reviews the potential for addressing this limitation through using organization-centered Multi-Agent Systems (OCMAS) in which agent interaction is designed around macro-level concepts such as 'organizations', 'groups', 'communities', 'roles.' Although the use of organizational metaphor in agent-based application is still in its infancy, there are some emerging modeling tools that can be used to advance the existing agent-based applications into open MAS exhibiting dynamic and flexible characteristics of open, distributed system. The paper illustrates this potential using a proof-of-concept based on decision support requirements for highway maintenance management.

Key Words: Organization Abstraction, Knowledge Systems, Construction Supply Chains

INTRODUCTION

Despite the significant advances that have been in construction informatics, there are still key outstanding issues that impede the seamless flow of information and knowledge across distributed applications (Sierhuis et al. 2009; Preitula 1998). Significant factors include the explosion in the sheer volume of real-time data generated through the use of robotics, the emerging smart grid and other advances intelligent infrastructure systems. The resulting knowledge and information integration challenge is further compounded by the growing number of business operations being executed in a global context by multinational corporations. In addition to altering organizational time scales, such developments have also given rise to new organizational forms, complexity and environment. Some issues have been addressed through the evolution of sophisticated building information models. However, some issues still remain unresolved. The existing models interface with a number of discipline-specific applications. The complexities inherent in generating explicit and independent representations of knowledge structures within such distributed applications remain largely unresolved. To fully address the information and knowledge flow needs, there is a need for dynamic organizational models that capture the critical aspects of an open, heterogeneous environment. The key features of such a model are summarized in Table 1 (Clancey 1998; Clancey et al. 2002 & 2005; Klein et al. 2005; Sierhuis et al. 2009).

In the 1990s intelligent agent technology picked up momentum for its potential for handling the critical aspects outlined in Table 1. Agents present a distributed approach to locating, retrieving and integrating information, and therefore resulting in applications that co-operate, co-ordinate and share their information with other applications. Anumba et al. (2005) provide a detailed description of construction industry-specific agent-based applications. These applications demonstrate different ways through which Distributed Artificial Intelligence (implemented in the form of intelligent agents) offers an innovative approach to overcoming knowledge and information sharing challenges in the construction-specific operations. In all knowledge-driven applications, agents are deployed within the context of a multi-agent system (MAS) - a computational system in which two or more (homogenous or heterogeneous) agents interact or work together to perform a set of tasks or to satisfy a set of goals (Lesser, 1999). Such a system comprises (1) an environment, (2) a set of passive objects that can be associated with a position in the environment, (3) an assembly of agents, which are specific objects representing active entities of the system, (4) an assembly of relations linking objects (and thus agents), (5) an assembly of operations with which agents perceive, produce, consume, transform and manipulate objects and (6) operators representing the assembly as well as reaction modifications (Ferber 1999). A multi-agent system is therefore a consolidation of autonomous 'problem solvers.'

Table 1: Modeling an open, heterogeneous environment

Critical Aspects	Examples
Organizational structures	Dynamic entry and exit of actors
Behavioral complexities	Flexible roles, goals and tasks
Collaboration complexities	Formal and informal interactions, multiple teams or adhocracies through which actors perform individual or joint activities.
Regulatory components	Flexible representation of organizational norms, policies, laws and culture
Common understanding	Seamless flow of knowledge among actors through shared understanding of positions and arguments
Context awareness	Using, reasoning and communicate about the physical and virtual environment

The potential for using conventional agent-based application is a subject that has previously been covered extensively elsewhere (see Anumba et al. 2005 and Obonyo and Anumba, 2011) and will not be duplicated here. This paper discusses the potential for enhancing construction industry-specific agent-based applications such as the ones described in Anumba et al. (2005) using organizational abstraction. Many of the existing applications have been based on 'agent-centered multi-agent system' (ACMAS) models. This limits the extent to which intelligent knowledge systems can exploit the advantages of deploying a community of autonomous problem solvers. The benefit of using an organization-oriented approach is illustrated using a proof-of-concept that was implemented based on requirements for making strategic decisions in highway maintenance. The paper also includes a critique of the existing organization modeling platforms and also identifies aspects of the research to be advanced in follow-up activities.

EXEMPLARY USE CASE – PROVIDING STRATEGIC DECISION SUPPORT IN HIGHWAY MAINTENANCE

The use case outlined in the subsequent paragraphs is based on work done by the author while working as a Business Improvement Analyst for ABC Limited, a large company contracted to perform highway maintenance for UK's High Agency (HA). In 2001, the HA adopted a new type of maintenance contract - Management Agent Contracting (MAC). The types of maintenance activities undertaken by company ABC under the MAC agreement include: 1) Planned maintenance (e.g. road resurfacing, strengthening or replacement of structures such as tunnels and bridges); 2) Routine maintenance (e.g. pothole repairs or street light outages, response and repairs following collisions or spillages, cyclical tasks such as cutting grass verges, periodic inspections of the condition of road surfaces and structures, as well as identifying the need for maintenance); 3) Winter maintenance (e.g. gritting of roads, snow clearance and maintenance of the equipment used for those tasks), and; 4) Technology maintenance (emergency phone systems, road sensors, CCTV and communications systems for regional control centers).

The National Audit Office (2009) observed that there were some improvements to service delivery that could be attributed to the use of the MAC model. However, there were also some rises in costs, with routine maintenance costs increasing by 11 per cent above inflation since 2002-03 while expenditure on planned maintenance has risen overall by 5.5 per cent above inflation. A significant proportion of these additional costs can attributed to the use of static and closed knowledge systems. It is relatively easier to design intervention strategies, plan and schedule the use of resources for maintenance activities that are time-based, condition-based or preventive by nature than to plan for reactive maintenance. Reactive maintenance activities, being unpredictable, are generally disruptive to the existing plans and schedules. Depending on the severity of the incidence, the stipulated response can vary from 15 minutes (Category 1) to the action being designated as something to be done as part of routine maintenance at a late date (Category 2 or 3). There are financial penalties associated with not acting within the required response time. In addition, as the contracts are renewable, none performance could result in losing the contract. Needless to say, responding to incidents is given high priority with the primary focus being completion within the stipulated time. From the author's experience, conventional knowledge system (See Figure 1) for managing the work orders and allocating of tasks to different crews do not adapt easily to such disruptions.

Maintenance service providers have Incident Response Units (ISU). When not responding to an incident, the ISU crews perform routine and preventive maintenance activities. Failing to make strategic decisions on how to adapt to changes triggered by disruptive reactive maintenance activities affects the projected schedule of payments from the client as some work items will take longer than planned. Some incurred costs that risk not being recovered in the payment period during which they were incurred include the engineering designs developed for the work items left pending as the ISUs respond to incidents. There are some other payment-related factors that make scenario modeling in this use case advantageous. Under the MAC model, the maintenance provider negotiates lump sum payments for some work items. In this payment arrangement, the contractor is expected to absorb any additional costs that are incurred through the ISU crew being reassigned to an incident. Without having a strategy for ensuring that scheduled routine maintenance work is adversely impacted the contractor c

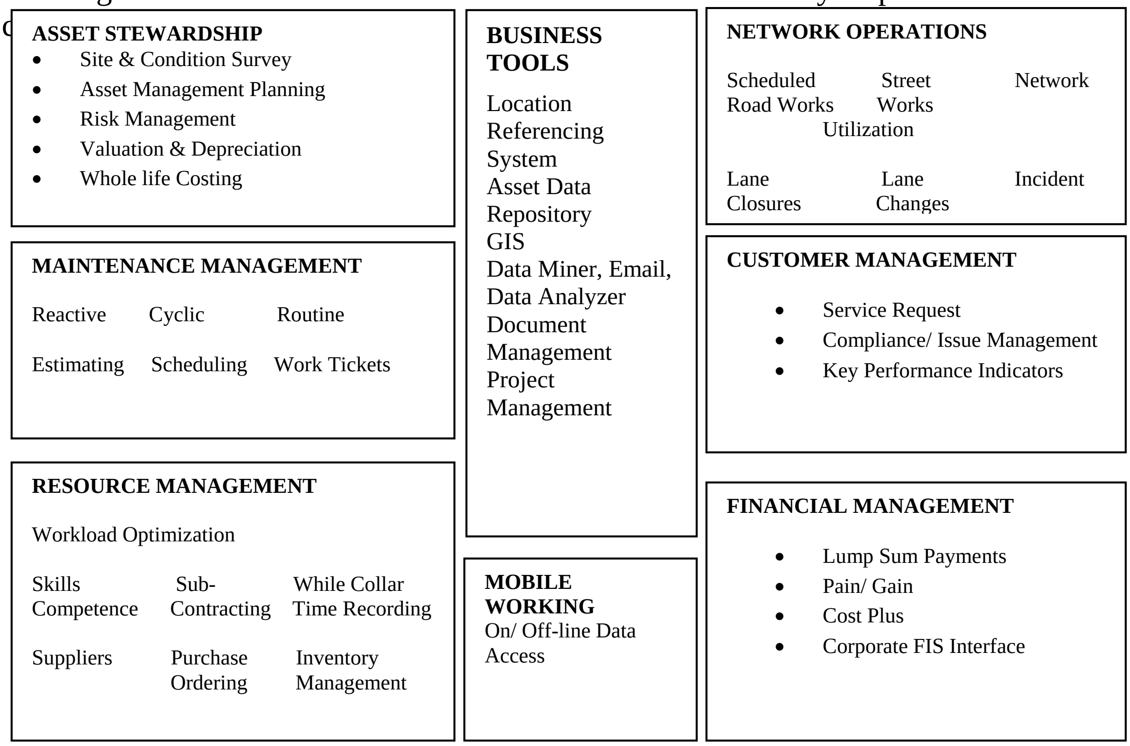

Figure 1: Features of Conventional Maintenance Management Knowledge Systems Adapted from Pitney Bowes Business Insight (2009)

Payment for some work items is governed by the “Pain/ Gain” agreement. Through this arrangement the HA and the service provide commit to sharing any cost savings or losses. For such items, both the provider and the HA benefit from work being performed at costs that are less than what was budgeted for. Some work items are governed by a Cost Plus agreement through which the contractor can negotiate for payments to cover costs over and above the original budget. The decision on whether or not to award payments for additional costs is at the discretion of the HA and there is therefore no guarantees that the contractor will always receive the requested adjustments to the original budget.

From the foregoing, it is clear that decisions being made can be greatly enriched through using a dynamic and adaptive intelligent knowledge system that can model different scenarios giving the maintenance service provider a global perspective of the net impact of decisions being made when responding to incidents. This is a requirement that can be addressed using agent-based approaches. Agent-based approaches implemented by different researchers for construction-industry specific applications can definitely improve the performance of the conventional knowledge systems being used by maintenance service providers. However, the benefits are not as extensive as they ought to be. Implementations such as the ones described in Anumba et al (2005) rely on ACMAS models, which focus on the internal mental state of an agent, the relationship between these states and the agent’s overall behavior (Ferber et al. 2003). In this approach, communications become speech acts whose meaning may be described in terms of the mental states of an agent as is evident in agent communication languages such as the KQML and FIPA ACL. Consequently, in the resulting agent-centered applications, agents can only communicate with one another within a closed system.

Since agents generally exist within the context of multi-agent software systems with some defined global behavior being derived from the interaction of constituent agents, the deployment of ACMAS-based applications greatly undermines the potential benefits of using a community of autonomous problem solvers (Jennings and Wooldridge 2000; Zambonelli et al. 2001).

Without this societal structure the patterns, the outcomes of the interactions are inherently unpredictable. Predicting the behavior of the overall system based on its constituent components is extremely difficult (sometimes impossible) because of the high likelihood of emergent (and unwanted) behavior (Jennings 2000). In agent-centered models, achieving interactions between agents from different designers assumes that one has knowledge of the primitives of communications (the "performatives" of the language) and the architecture of agents (for example, assuming that agents are behaving purposively in a cognitive way, using some kind of BDI (Belief-Desire-Intention) architecture (Ferber et al. 2003). ACMAS-based agents do not have access to such constraints, which are often specified as ISO-like standards. They also lack the ability to either accept or refuse to follow these standards. For these agents to communicate, they must therefore be deployed using the same language and very similar architectures. There has been a growing interest among researchers to resolve this problem through modeling agent-based systems using organizational abstractions. The author has in a different publication (Obonyo and Anumba 2011) provided a detailed review of pioneer and emerging organization-centered multi-agent approaches which will not be duplicated here. The subsequent section discusses the potential for addressing an organization-centered multi-agent approach to address some of the complexities in the highway maintenance use case.

ORGANIZATION-CENTERED MULTI-AGENT APPROACH FOR INTELLIGENT KNOWLEDGE SYSTEMS

The challenges inherent in the highway maintenance scenario described in the preceding section mirror the challenges for railway maintenance observed by Mensonides el al (2008). Their proposed solution was based on the use of OperA (Mensonides et al. 2008) organizational agent models. Since agent-based systems can be naturally viewed as computational organizations, organizational abstractions and the associated metaphors and concepts should play a key role in the analysis and design of MAS (Jennings 1999; Zambonelli et al. 2003). In this approach, issues such as open organization modeling, argumentation frameworks, teamwork, and culture are captured using macro-level concepts such as 'organizations', 'groups', 'communities', 'roles' (Ferber et al. 2003; Zambonelli and Parunak 2002, Sierhuis et al. 2009).

Despite the similarities in the use cases, the author favors the use of AGR (Agent-Group-Role) models over the approach adopted by Mensonides el al's (2008) models. AGR models have been deployed within MADKIT (URL2) which is a stand-alone, java-based platform. The OperA approach was implemented as part of the EU-funded ALIVE project (Aldewereld et al. 2010). The ALIVE was a project directed at implementing a suite of adaptable, organization-aware, service-oriented Computing applications. It is therefore difficult to deploy standalone organizational-models based on the OperA approach. In subsequent research efforts, the author will experiment with the use of the ALIVE suite of applications.

The author has previously reported MADKIT (URL1) to deploy an organization-centered MAS construction e-business prototype for the procurement of concrete (see Obonyo and Anumba 2011). As indicated in a preceding section, structural repair of the infrastructure is an integral part of maintenance activities. Suppose structural damage occurred through an incident and there will be a need to urgently identify the most optimal strategy for getting the required material (concrete, in this example). In the implemented proof-of-concept requests for bids, identification of suitable suppliers and the negotiation to close the transaction are all be done using MADKIT's macro-level concepts as shown in Figure 2. Because the agent-to-agent interaction in not based on the mental states of agents, an infinite number of options can be explored through agentifying existing targets using wrappers.

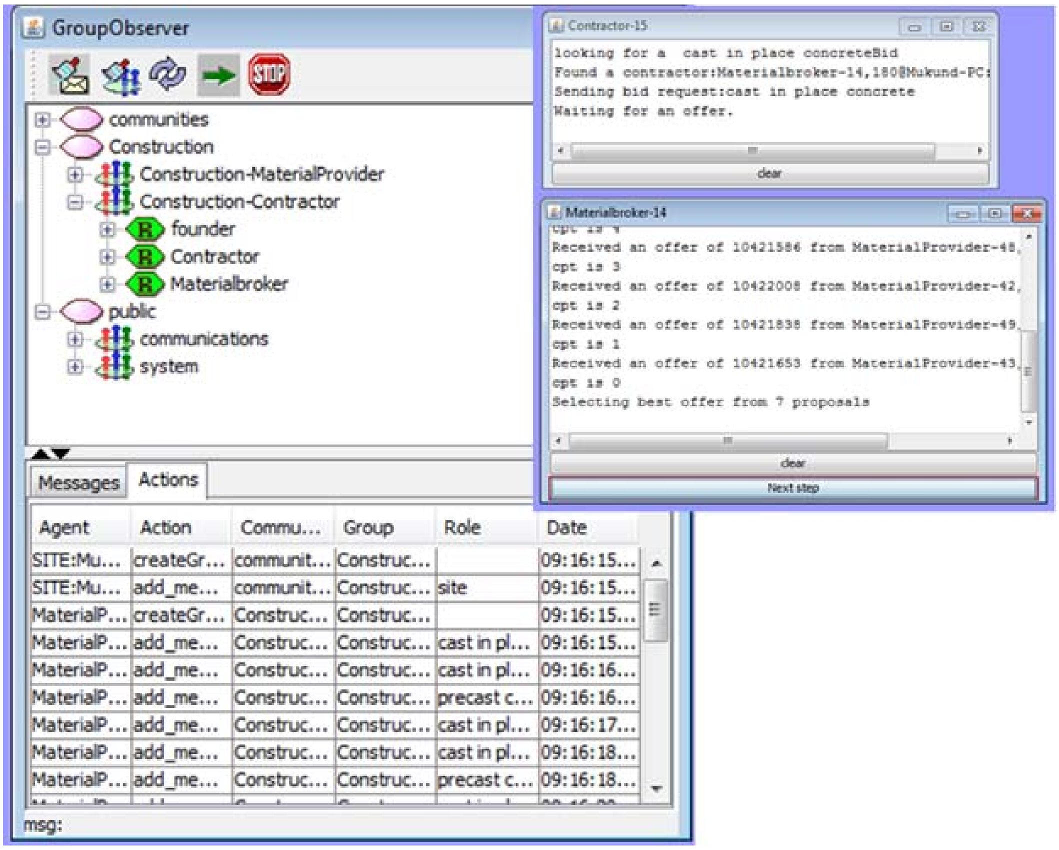

Figure 2: Organization-Centered Agent-based Concrete Procurement

The author has also implemented a proof-of-concept based on the MADKIT platform for modeling different scenarios for dynamically assigning work items to groups of maintenance crews (see Figures 3 and 4). Within this organization-centered MAS, new work items arising from incidents and disruptions to planned maintenance activities as incidents occur can be competitively assigned dynamically to a large team of distributed crews using negotiations governed by macro-level concepts such as 'organizations', 'groups', 'communities', 'roles.' The distributed units across all contracts being managed from dispersed locations are structured into communities that agents representing the different units can join and leave at will. The agents' interactions are based on the different units assuming one of the following roles: broker, client or provider. The successful negotiation that results in the dispatch of an ISU in response to an incident creates a demand for a crew to take on the activity that the ISU crew was previously performing. This becomes a request bid item for other crews. Through pre-specifying the preferred hierarchy of importance for the maintenance activities, pending work items can be dynamically re-negotiated multiple times to assess the global impact of different adjusted schedules and plans when the existing ones are disrupted.

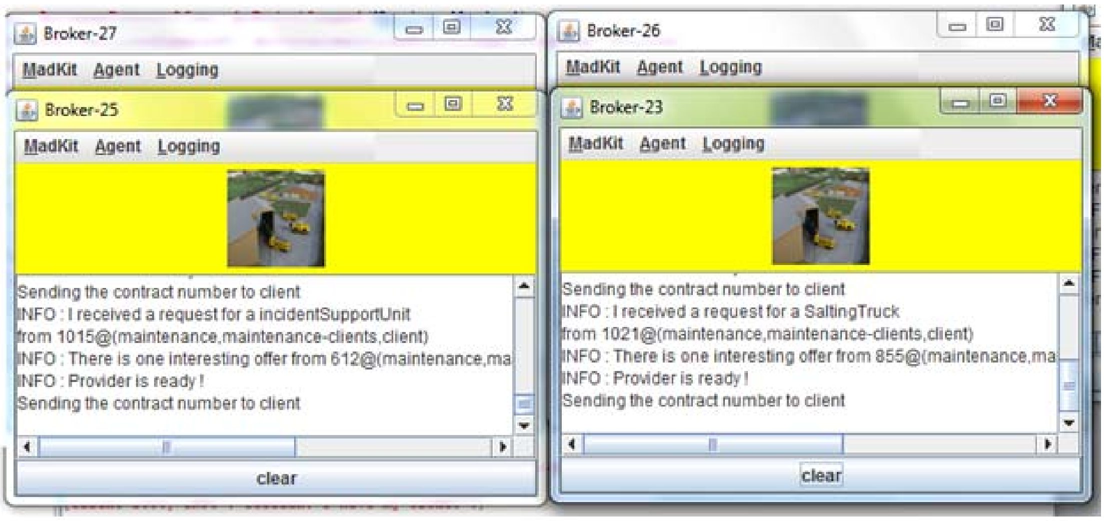

Figure 3. Work Assignment Based on Organization-Centered Models

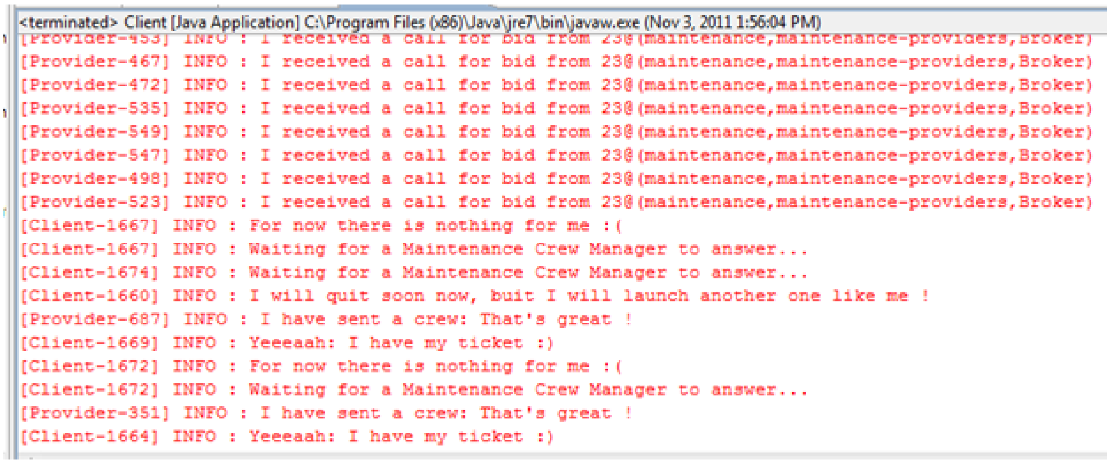

Figure 4. Extract of Agent-Group-Role-Based Work Assignment Negotiation

DISCUSSION AND CONCLUSIONS

The discussion in the preceding section has demonstrated the superiority of using organizational-centered models which allow flow of information across agents without using their internal mental states. In the implemented proof-of-concept communication was achieved though using the MADKIT platform, an implementation of Ferber et al.'s (2003) Agent-Group-Role approach in which MAS are designed using only organizational concepts such as roles (or function, or position), groups (or communities), tasks (or activities) and interaction protocols (or dialogue structure). This approach gives developers the ability to build organizations as frameworks where agents with different cognitive abilities can interact. The resulting organization-centered MAS applications reflect the dynamic and flexible characteristics of an open, distributed system. This approach can therefore address many of the challenges inherent in existing decision support knowledge systems for highway maintenance. Specific examples have been outlined in Table 2.

Table 2. Enhancing Existing Systems

Known Limitations	**Required Change**
Rigid operations driven by timetables	Dynamic scheduling of operational serviced and maintenance jobs triggered by events
Homogeneous processes for a single client	Heterogeneous processes to comply with a number of contracts
Top-down planning and scheduling	Negotiation between parties with conflicting interests
Rigid maintenance allocation based on head office planning	Dynamic negotiation based on the condition of the highway assets

Information from Review by Extracted from Mensonides el al (2008)

The organization-centered MAS models override some of the complexities inherent in generating explicit and independent representations of knowledge structures within distributed applications. This notwithstanding, it is important to bear in mind that organization-centered agent-based modeling is still in its infancy stage. There are, therefore, no unified robust organizational models that can adequately capture all facets of organizational structures with actors and roles, requirements and objectives. Researchers have tried to address the outstanding issues (see the review by Sierhuis et al. 2009). Some noteworthy examples include the Organization Model for Adaptive Computational Systems (OMACS) and the Multi Agent Systems based on Quadrants (MASQ). OMACS focuses on the definition of knowledge that can be used to design systems that can self-organize (Oyenan and DeLoach (2010). OMACS is designed using the Organization-based process Framework (O-MASE) and deployed using the Organization-based Agent Architecture (OBAA). MASQ is an extension of Ferber's (2003) Agent-Group-Role Models. The MASQ meta-model defines four perspectives of interaction based on two axes: internal/external and individual/collective (Dinu 2009). It provides an integrated way of viewing agent-based interactions which incorporates several elements that are often studies in isolation (Dinu 2010).
The deployment of both OMACS and MASC into universally-applicable, organization-based models requires verification and validation in different use cases based on the requirements of a specific disciplinary domain. In subsequent research efforts, the author will enhance the proof-of-concept implement for highway maintenance through assessing the feasibility of using an agent-based wrapper to enrich these models with real-time data captured from sensors being used to monitor the structural health of the infrastructure.

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