Agents, Availability Awareness, and Decision Making

Stephen Russell
Department of Information Systems
University of Maryland Baltimore County
Baltimore, USA
1- 410-455-3206
stephen.russell@umbc.edu

Abstract

Despite the importance of resource availability, the inclusion of availability awareness in current agent-based systems is limited, particularly in decision support settings. This paper discusses issues related to availability awareness in agent-based systems and proposes that knowledge of resources' online status and readiness in these systems can improve decision outcomes. A conceptual model for incorporating availability and presence awareness in an agent-based system is presented, and a practical framework operationalizing the conceptual model using JADE is proposed. Finally, the framework is developed as an agent-based decision support system (DSS) and evaluated in a decision making simulation.

Keywords: Intelligent Agents, Availability Awareness, Decision Support

1. Introduction

Context aware computing has gotten a great deal of attention in recent years as mobile computing and pervasive computing technologies have advanced. The scope of context aware computing is broad and covers a variety of subject areas including location awareness, environment awareness, preference awareness, and usability. Context refers to the physical and social situation where a computational device is being used. Context aware computing strives to acquire and utilize information about the context of computing devices and thier users in order to provide computational services that are appropriate for the user, place, time, and environment. This concept of context extends to intelligent agent-based systems (Moran et al. 2001). Agent interactions take place in a rich context of previous actions, individual beliefs, invisible states and different perspectives about which agents must reason in order to interpret the settings in which they find themselves (Benerecetti et al. 2001).

Intelligent agent research has invested a great deal of attention in approaches that enable or utilize context awareness. As a result, many agent systems employ some form of context awareness (Payton et al. 2004; Plaza et al. 2001). However, few of these systems deliver this context information directly to the user. More specifically, the context information is used by the agents to tailor users' system experiences without users' direct knowledge of the details and the context information is not provided directly to the user. In a decision support scenario, context information may be extremely valuable to the end user and particularly in distributed agent systems it should not be assumed that the decision maker is aware of the context in which the decision support environment exists. Of critical importance to decision makers is awareness of the status and availability of decision specific resources. Little attention has been given to the effects of agent, resource, data, and system availability on decision making and agent-based decision support systems.

The objective of this paper is twofold. The first objective is to propose an agent framework that can provide online status (presence awareness) and readiness (availability awareness) information to a decision maker regarding the agents and their resources. The second is to determine whether awareness information can enhance a decision support system (DSS); providing better decision outcomes. This paper examines what is necessary to enable this capability and what effect it will have on decision outcomes. In Section 2, a discussion of prior work and background on presence and availability awareness is provided. Section 3 illustrates agent presence and availability awareness in a decision making context and presents a theoretical model that incorporates these concepts as part of an agents functional components. In Section 4, the theoretical model is mapped to the operational framework that will be evaluated in an experiment testing the effects of presence and availability awareness on decision making. Section 5 explains the experiment evaluating the model and framework. Section 6 presents the results of this experiment; finally concluding with a summary in Section 7.

2. Related Works

To be effective, mobile or distributed systems require some context aware components (Want et al. 1995). From a user's perspective, concepts that fall under context awareness include changes in a user's physical state and location, workflow, preferences, or resource interests. This paper does not address all of the issues considered as context awareness; instead, the focus is on presence and availability awareness, in terms of users, agents, data, and system resources. Within context awareness it is important to provide a working definition of presence awareness. In this paper presence awareness is defined as knowledge of whether agents, data, or system resources are online and connected for communication. Presence awareness provides knowledge of an agent or resource's state, in terms of connectivity. Presence awareness is the basis for availability awareness, since knowing if an agent or its resources are online is the first step in determining availability for use. Succinctly, availability awareness is knowledge of an agent's or resource's readiness to be used.

Presence awareness gained a great deal of popularity in real-time communication applications such as instant messaging (IM). All IM clients incorporate a form of presence awareness so that users can be made aware of when a potential communication partner, or "buddy," is online. Many of these clients also include availability awareness using techniques such as keyboard and screen saver monitoring. From a research standpoint, most of the studies on IM have been on its utility as a communications medium (Griss et al. 2002; Kwon et al. 2006; Wang et al. 2004).

Favela's (2002) research differs from the main body of instant messaging communication research. Favela's group investigated using instant messaging as a presence and availability awareness tool in agent-based systems by creating AIDA, an instant messaging and presence awareness client for handheld devices. What is unique about Favela's efforts is his treatment of network resources, such as scanners and printers, as presence aware items. By extending the notion of presence availability to documents and other resources, AIDA offers new opportunities for casual encounters in a community of co-authors. For instance, when a user notices that a document is in use, he/she might send a relevant message or even join his/her colleague in a synchronous collaborative authoring session. In contrast to the work in this paper, Favela's work, while innovative and unique, does not focus on decision making. His application of presence awareness concentrates on location contexts (i.e. proximity to resources and basic online-offline status of resources). His work does not examine how knowledge of presence and availability would affect users or decisions; rather his group studied the implications of a hybrid software-hardware architecture supporting document management and collaboration.

In the decision support domain Kwon's (2004) work attempts to address context issues with an agent-based mobile DSS that includes context awareness called ubiDSS. Kwon explains that the ubiDSS is characterized by its ability to identify decision makers even though they are moving, and to allow them to get solutions through any portable devices, in any workplace. The ubiDSS model implemented by Kwon is specifically focused on context awareness, but Kwon's context awareness subsystem is user-centric and only delivers context information related to a users' location. It also does not include presence or availability awareness with regard to resources needed for decision making.

Burstein et al. (2005) integrate context awareness, mobile software agents and decision support concepts by proposing a real-time DSS for the emergency healthcare domain. This work proposed an integrated framework including client server components that interact with mobile devices located on an ambulance or emergency medical personnel. Context awareness was accomplished by connecting the mobile PDA device to a web server, where the web server provides an interface to the underlying federated multi-agent architecture. In this research, there are only two mobile nodes, the remote PDA in the ambulance and the hospital assistant. The central component of the architecture is a "road authority" website that is accessed to determine context and availability of the agents. Each hospital has agents that provide access to patient records. The agent on the mobile device interacts with this hospital assistant agent to share information about the hospital doctors, nurses, and beds. The hospital assistant agent serves as the 'link' between the mobile ambulance agent and the other static agents representing the various hospitals/specialty clinics. The primary task of this agent is to travel to the various hospital nodes and retrieve the latest availability of resources.

A significant limitation of Burstein's system is seen in the fact that the context information was manually provided from the end user. Moreover the agents did not provide any feedback on the the status of themselves or their resources. In contrast to Burstein's work, Aneiba et al. (2006) take a different perspective on mobile agent-based DSS and emphasize data retrieval, by researching a multi-agent DSS to support wireless information management. Wireless information management involves the capture, digitization, organization, transformation, and presentation of information over a wireless link. Aneiba's efforts developed a decision support model called Wireless Information Decision Agent (WIDA) whose decision support objectives are to reduce the waste of wireless resources (e.g. bandwidth, memory, and power), increase revenue opportunity by using resources as efficiently as possible, use the communication time more efficiently, and improve user satisfaction with network usage. While Aneiba's work improved the availability of data for retrieval, it lacks of any presence or availability awareness.

Generally, agents have been researched extensively in supporting decision support systems. Recent approaches using agent architectures have employed the agents in roles such as simulations, communications, information retrieval, or provide decision support (Ajenstat 2004; Labrou et al. 1999; Luo et al. 2002; Mistry 2003). Additionally, several projects integrate agents, DSS, and web-based interfaces (Dong et al. 2001; Power 2002; Wooldridge 2002). However, the literature on presence and availability aware agents applied to decision support is sparse.

Presence and availability awareness are critical to any-time, any-where access to support systems regardless of whether the user, agent, or resource is busy, weakly connected via a high-latency, low-bandwidth network (e.g., cellular), or completely (yet temporarily) disconnected. For decision making, particularly time-sensitive decision making, providing this information to the decision maker can change the course of a decision maker's actions and subsequent interaction with a DSS. In contrast to this previous work, the research described in this paper differentiates itself from other work by examining how knowledge of agents' and their resources' availability can affect decision outcomes. Rather than addressing the issues that cause agent availability problems such as network outages or high processing loads, a method for incorporating awareness in an agent-based DSS is proposed.

3. Conceptual Model

In a decision making context, the effects of presence and availability awareness introduce additional choices in the decision making process. Consider the following example where a business decision maker must make a decision within a short period of time. At the outset of this process the decision maker has an initial choice to seek support or not. If the decision maker chooses to use support, that support and necessary resources may or may not be available. If the support/resources are unavailable, then the decision maker has a second choice: to wait or not to wait for them to become available. It is this second choice that presence and availability awareness aids. If the decision maker has insight to how long the support or resources will be unavailable, then the decision maker can make an informed choice about how to proceed.

These same "inter-decision" choices extend to intelligent agents. Albeit their choices are decided programmatically a priori (which may be a worse condition in the absence of presence and availability awareness). In the same manner that the example decision maker was subjected to the unavailability of necessary resources or support, an intelligent agent must also contend with system interruptions, such as network congestion, processing load, and user-based delays. This is a particularly critical issue in federated agent system, because of the centralized control and potential inter-agent dependencies.

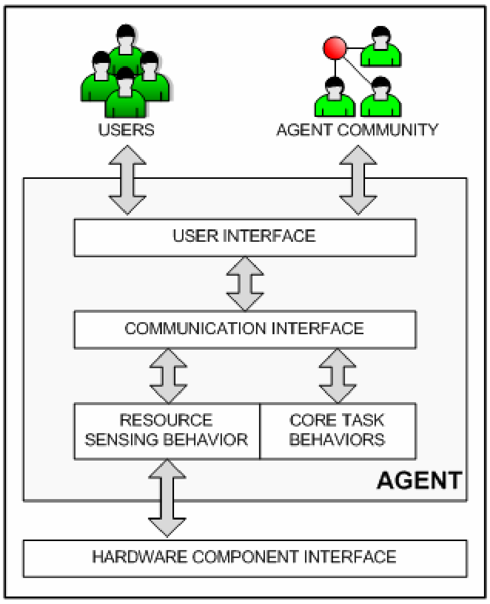

Figure 1. Agent with presence and availability awareness

The conceptual model shown in Figure 1 proposes that agents need to incorporate more than simple presence awareness; they need to have availability awareness and provide this information to the user, as well as utilize this information themselves.

This capability is essential in the cases where decisions are time constrained and necessary resources may not be local to the system. With advances in collaborative and mobile computing, the issue of non-local resources extends beyond inputs and data, to include even system users themselves, who may not be always available for action initiation, feedback, and output. Typical agent systems are programmed a priori to handle unavailable users, system interruptions, and outages with error messages or system failures; thereby limiting the assistance provided by the system when unaccounted interruptions occur. By including presence and availability awareness as an agent behavior, resource contention, delays, and unavailability can be dealt with in real-time when the impact of these events are at their highest cost. The model shown in Figure 1 includes presence and availability awareness as a functional part of an agent's internal behavior.

Many agent designs include behaviors that enable agent functionality, and these behaviors define the re-useable actions that agents possess and execute (Allbeck et al. 2002; Decker et al. 1997). Figure 1 illustrates an agent enabled with a resource sensing behavior, in addition to its core task behaviors. The resource sensing behavior pays attention to hardware and services such as network interfaces, the system processor, or other resources beyond the agent's immediate hardware component interface. Information (shown as arrows in the figure) gained from this behavior's activity is provided to system users and the agent community appropriately depending on the agent's primary behaviors. The resource sensing behavior can also provide awareness of system users in the same manner as other resources; again providing this information back to other agents and users. While not shown explicitly in the conceptual model, the core task behaviors may utilize the hardware component interface to support its activities if necessary.

It is important to note that the resource sensing behavior should provide more than simple presence (online/offline) status information. The resource sensing behavior should provide information about if and/or when the resource will be available. The obvious question is: how can availability knowledge can be obtained? Research from other domains provides answers to this question. The first domain is high-availability computing. Research in this area has already identified methods to monitor and evaluate hardware related statuses such as power (Chakraborty et al. 2006; Rahmati et al. 2007), network characteristics (Roughan et al. 2004; Shahram et al. 2006), and computer components (Brown et al. 1999; Weatherspoon et al. 2005).

The second domain provides status of resources that can be considered software services. Software services provide a layer of abstraction for a full range of programmable functions and data. Research in the area of web service composition and quality of service (QoS) can provide agents with knowledge of these types of resources. Quality of service is often defined as the probability that a network or service will meet a defined provision contract. This probability could be used by agents to forecast the likelihood of resource interruption as well as potentially quantitatively predict outage durations. There is a significant amount of research studying applications using QoS and QoS monitoring for service level agreements, adaptation to changing system conditions, and web service composition (Ali et al. 2004; Loyall et al. 1998; Menasce 2004; Thio et al. 2005). Web service composition is a particularly active research area, rich with solutions for service availability, because of the critical nature of this information for process scheduling and execution planning (Peer 2005; Pistore et al. 2004).

A third domain provides availability information on humans or users of a decision support system. From the perspective of "users as a resource," human computer interaction research has provided several availability-oriented solutions. Most of the efforts have focused on detecting *if a user is* and not necessarily *when the user will become* online and available (Begole et al. 2004; Danninger et al. 2006; Muhlenbrock et al. 2004). However, there are probabilistic models that can provide forecasts for humans' presence and availability. Horvitz et al. (2002) developed a prototype service intended to support collaboration and communication by learning predictive models that provide forecasts of users' presence and availability. To accomplish this, they collected data about user activity and proximity to multiple devices and combined this with analyzed content of users' calendars.

Because the research conducted in these other domain provides viable solutions for obtaining quantitative data about resource availability, the model and framework proposed in this paper does not focus on this issue. Instead, the proposed model and framework provide the basis for integrating presence and availability into agent-based systems generally and agent-based DSS specifically. Moreover, this work examines the effects of awareness on decision outcomes when using agent-based DSS with and without awareness capabilities. In the following sections an operationalized framework is presented and evaluated.

4. Agent Awareness Framework

As a practical implementation of the conceptual model, a FIPA (2003) compliant Java Agent DEvelopment Framework (JADE) (Telecom Italia Lab 2007) architecture is adopted. JADE is a software framework that simplifies the implementation of multi-agent systems through a middle-ware that complies with the FIPA specifications. As defined in the theoretical model, the awareness capabilities of the framework are implemented as agent behaviors. Figure 2 illustrates the agent framework.

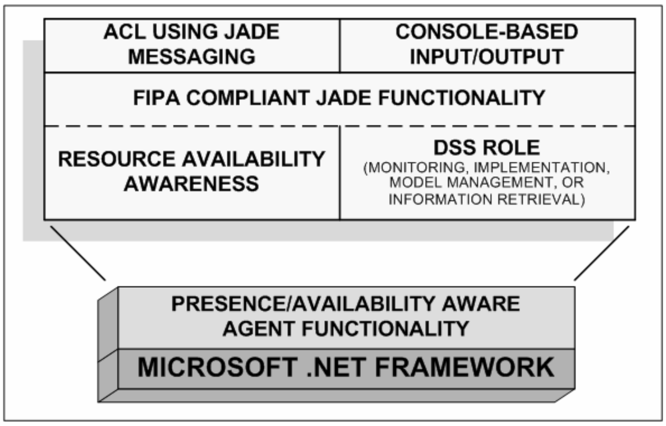

Figure 2. Presence and Availability Aware Agent Framework

The bottom portion of the Figure 2 shows the significant framework elements and the top is a zoomed view of the operational agent portion of the framework. While shown at the foundation of the block diagram, the Microsoft .Net framework is employed as the "glue" for the agent internals. This approach allows other agent components to be developed in heterogeneous languages that provide the most appropriate capabilities for that component. The ability to utilize a language and platform agnostic development environment gives the framework a significant advantage over existing decision support and multi-agent architectures, which are commonly developed using one language such as JAVA (Russell et al. 2005).

In this implementation, the agent uses a modified XML-based ACL that is transported over the intrinsic JADE messaging protocol. In other implementations the modified XML-based ACL could be replaced with user-defined ACLs transported using other FIPA compliant protocols. Similarly, while Figure 2 shows the user interface as console-based, this too could be replaced with web-based, desktop-based, or other interfaces.

By implementing the resource availability awareness as a behavior using the .Net framework it is possible to "plug in" many of the existing solutions as modules that could be integrated at a source code level or dynamically loaded during run-time execution. Furthermore, this approach would allow a single agent to support more than one awareness capability or functionality. The .Net framework also provides a significant amount of "out-of-the-box" system awareness functionality in its library integration with performance counters (Gunderloy 2007) and simple network management protocol (SNMP) interfaces (Crowe 2002). The Microsoft performance counters provide detail monitoring data for system components such as CPU utilization, disk utilization, and memory consumption. It also provides extensions for applications such as web servers, SQL databases, and other application software (Microsoft 2003). SNMP provides similar capabilities for other non-Microsoft platforms (Teegan 1996).

5. Experimentation

This study raises the research question: should the awareness of when or if a resource will be available, for use by an agent-based DSS, be used to affect decision making outcomes? As mobile and pervasive computing environments increasingly become the norm and system resources become more likely to be distributed (e.g. computing grids and distributed databases) the relevance of this research will be progressively more significant. The systems in these environments will be relied on to provide decision makers with guidance and advice for not only essential, time-sensitive, business decisions, but also commonplace, frequently-made, personal decisions. Based on the above discussion, we formulate the following hypothesis: *agents with resource availability awareness will improve decision outcomes based on correct advice provided by an agent-based DSS and accepted by the decision maker*.

To evaluate this hypothesis, a decision making experiment was conducted. This experiment operationalized the framework presented in Section 4 in an implementation that isolated the effects of resource availability awareness. To evaluate these effects, a decision problem was constructed where a stock is purchased each day from the list of Standard & Poor's 500 stocks (S&P 500). The agents were implemented as a DSS to aid this process for the decision maker.

The experimental design limited the amount of time in which to choose the stock to 5 minutes and made a necessary Internet resource intermittently unavailable. To execute the experiment a simulated decision maker was coded that would always take the advice provided by the DSS, if it was available. This decision maker has a simple strategy for deciding which stock to purchase each day. In equity trading, there is a concept that volume precedes price (Fontanills et al. 2001) and this is the purchasing strategy that the decision maker employs. The agent-based DSS has the capability to identify from the list of 500 which stock has the highest volume and this is the advice provided.

In the DSS there are two agents: 1) an interface agent whose responsibility is to identify the high volume stock and communicate with the decision maker and 2) an information retrieval agent responsible for contacting an Internet resource that will provide information about the trading volumes for all 500 stocks for a given day. Figure 3 illustrates the two experimental cases that were evaluated. In one case, the decision-maker has no knowledge of when or if data will be available (control) and in the second case, the agent has knowledge regarding the availability of the resource that provides the stock volumes for the day (treatment). For both cases the Internet resource randomly may be available immediately, become available after a period of time, or be completely unavailable.

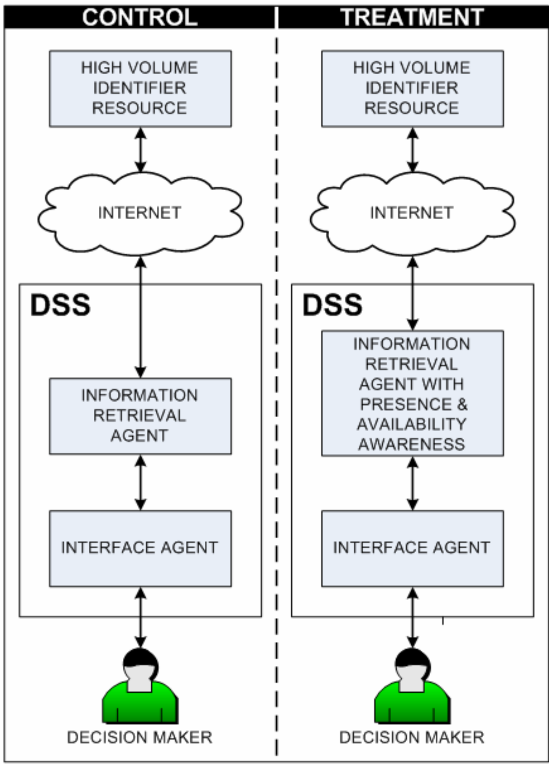

Figure 3. Experimental implementation

The two experimental cases had 5 variables that determined the conditions of the scenario, as shown in Table 1. All of these values were randomly generated for each run of the experiment. It was assumed that each input value would follow a standard normal distribution with a mean of 0 and a standard deviation of 1. To incorporate the diversity of inputs from a population of users and scenario conditions, each variable was assumed to follow a standard normal distribution with a mean of 0 and a standard deviation of 1. The choice of a normal distribution was based on the Central Limit Theorem, which roughly states that all distributions approach normality as the number of observations grows large (Barron 1986; Davidson 2002).

VARIABLE	FUNCTION
Take_Advice	This is a 1 or 0 value determining if the DM who randomly takes the DSS advice decides to take the advice. If 1 then the DM takes the advice, 0 DM doesn't.
Data_Avail	This is a 1 or 0 value determining if the data is immediately available. If 1 then the data is available, 0 it is not. In the control case, if this is 0 then the DM-Wait and Delay_Amt values are used.
DM_Wait_YN	This is a 1 or 0 value determining if the decision maker waits for the data to become available or decides to choose a value before it becomes available. This variable only applies to the control case.
DM_Wait	Decimal value between 0 and 5 minutes that determines how long the DM waits. This variable only applies to the control case.
Delay_Amt	Decimal value between 0 and 10 minutes that determines how long the data will be unavailable. This data is sensed by the treatment agent.

Table 1. Simulation scenario variables

If the DSS cannot provide advice because the resource is not available within the allotted 5 minutes, the decision maker randomly selects (using a normal distribution) one of the 500 hundred stocks for that day. The experiment was run 100 times; once a day, for 100 days. Each day there is only one stock with the highest volume and the volume of the stock (as well as its name) is recorded for each run. The stock volume quantity was selected as an objective measure of the quality of the DSS advice. Since the decision maker always takes the advice, the overall volume can be used to determine whether the decision outcomes over all the runs are improved, quantitatively testing the hypothesis.

6. Results

The results of the experiment were analyzed using SPSS and the hypothesis was tested. Table 2 shows a summary of the experiments' results. The table describes 4 measures for each run group (availability ***known*** and ***unknown***): number of correctly identified stocks (***correct***), defined as the stock with the highest volume for the day; total volume (***total vol.***), the sum of the volume for all 100 days; average volume (***avg. vol.***), the average volume per day; and the total square error (***total sq. err***), the sum of the error between the selected volume and the maximum for each day. From this it can be seen that the runs with an availability awareness enhanced agent that provides awareness information to the decision maker, have more correct decisions, higher total and average volumes, and a lower mean square error (difference between the possible maximum volume and the volume of the chosen stock).

Known Correct	Unknown Correct	Known Total Vol.	Unknown Total Vol.	Known Avg. Vol.	Unknown Avg. Vol.	Known Total Sq. Err	Unknown Total Sq. Err
79	66	7.63E+09	6.13E+09	7.63E+07	6.13E+07	1.80E+17	4.27E+18

Table 2. Experiment results summary

To evaluate the hypothesis, the control and treatment runs were compared using paired t-tests for volume and square error. Table 3 shows the results of the t-tests. The awareness-enabled agent outperformed the "unaware" agent with higher total volume and lower square error. For both measures, the t-test results were significant with alphas lower than .05, supporting a rejection of the null hypothesis.

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Upper	95% Confidence Interval of the Difference: Lower			
VOLUME Known vs Unknown	1.498E+07	4.824E+07	4.824E+06	5.403E+06	2.455E+07	3.104	99	0.002
SQ. ERROR Known vs Unknown	-2.476E+15	1.198E+16	1.198E+15	-4.853E+15	-9.948E+13	-2.067	99	0.041

Table 3. Hypothesis testing

The results demonstrate a significant improvement in decision outcome, measured quantitatively by volume. In summary, the results show that the availability aware agent provided better advice, leading to better outcomes, for the simulated decision maker that always took the provided advice. The general implication for agent-based systems is not necessarily dependent on whether the decision maker (in this case an agent) would take the advice because this would be handled programmatically. The results of this study suggest that inter-agent availability awareness would deliver similar benefits. In terms of generalizability, this experiment illustrates that availability awareness can improve decision outcomes in agent-based DSS when decision-related resources are intermittently available. However, the simulation should be expanded for a larger number of runs and include cases where the decision maker does not take the advice.

7. Conclusion

As this research study illustrates, agents' awareness of resources' presence and availability can lead to different decision outcomes. In addition to presenting a theoretical and practical model that incorporates presence and availability awareness, this study examined the effects of these concepts in an operationalized agent-based DSS supporting a decision making process. The issues of availability awareness are significant, but unstable computing environments may suffer from complete outages and interruptions where the disruption goes beyond the time boundaries of the decision opportunity. In this case, awareness of the availability would have a limited effect. Further study is necessary to evaluate the implications of awareness in extreme cases of unavailable resources.

This study did not integrate any of the potential solutions for quantifying a resource's availability, instead implementing its own. This was done to isolate the effects of availability awareness. However, additional work should be conducted to demonstrate the applicability of these other methods of quantifying resource availability. This study also assumed that scenario conditions would follow normal distributions. A variety of other distributions are possible, including the uniform, binomial and Gamma, distributions. Further studies, then, should examine the sensitivity of the results to changes in distributions.

The results of this study confirm that an agent-based DSS enabled with awareness improves decision making when compared to an agent-based DSS without it. Since the results are expressed in volume of shares traded, the findings provide an objective measure of determining the relative decision value of the presence and availability awareness. The results of this research should be generalizable to other agent-based systems. Future work is planned that will extend the system developed in this research with additional functionality such as user availability awareness components. This system will be used to expand this study, examining the limitations noted above.

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