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MASOS: A MULTI-AGENT SYSTEM SIMULATION FRAMEWORK FOR SUSTAINABLE SUPPLIER EVALUATION AND ORDER ALLOCATION

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ABSTRACT

Purchasing activities consume more than half of manufacturing and trading organizations sales capitals. Effective procurement is tied with efficient and highly accurate collection of data needed for purchasing the right material with the acceptable quality from appropriate suppliers. Supply chain management (SCM) consists of complex networks of distributed actors in which the problem of identifying the appropriate suppliers and allocating optimal order quantities based on the Triple Bottom Line (TBL) attributes is strategically important. However, implementation of an autonomous and automated assessment that can incorporate dynamics and uncertainty of the whole supply chain during the assessment period is not addressed. In the current research paper, a novel framework is designed and proposed to narrow the aforementioned gap. Agent technology has been incorporated in the developed framework to decrease the supplier chain uncertainty by decreasing human interactions and automating the process of supplier evaluation and order allocation.

1 INTRODUCTION

Manufacturing a product that can increase an organization's profitability and maintain its competitive advantage in the market depends on many important factors. Coordination and sustaining an appropriate relationship among Supply Chain (SC) actors specifically manufacturers and suppliers is one of those factors that of course can be difficult to achieve. A domain like SC is repeatedly subject to fundamental alterations. Although many researchers have proposed mathematical programming models to facilitate the sourcing decisions, these models are static and cannot respond to uncertain market conditions. In a well-known review paper by Lee and Kim (2008) in the area of SC and manufacturing; they pointed out that a possible solution to this gap would be applying Multi-Agent Systems (MASs) in order to decrease the response time and to maximize expected profit. In a more recent literature review conducted by Ghadimi and Heavey (2013), it was concluded that uncertain and dynamic features of agents' external environments such as uncertainty and dynamics in SC network environment (from the perspective of manufacturer-supplier dyad) can be considered as one of the most relevant area of real-world application for Agent-Based Modeling and Simulation (ABMS). Those aspects of network behavior which change over time can be especially captured by MAS implementation. Autonomous and distributed characteristics of agents improve a SC system in a robust way by adding the capability of dealing with changes in a continuous manner without any degradation in the overall system performance (Jain, Wadhwa, and Deshmukh 2009). In a well-known work in intelligent supplier selection domain, Valluri and Croson (2005) noted that common managerial problems in modern organizations are firstly how to select capable supply partners and secondly in what manner to keep them motivated to sustain their relationship after their selection
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In real-world situations, various elements such as lack of information, uncertainties in information flows, demand forecasting errors and etc. can cause extreme variability in the type of order, order quantity and order frequency. Unfortunately, these variations are realized due to the lack of coordination in the SC. Jain, Wadhwa, and Deshmukh (2009) claimed that agent technology therefore is very suitable to support collaboration in SCM. Supplier selection operations as an inevitable part of SCM is getting more challenging due to the information overflow and rapid development of e-commerce. Efficient and accurate decision-making cannot be achieved using traditional subjective selection due to limitations in accessing information. Therefore, the introduction of Multi-Agent technology, the use of its distribution, autonomy, mobility, intelligence and self-learning and other characteristics leads to improve the intelligence of the supply chain management process, and to provide the support for the automation and intelligence of supplier selection decisions (Mian 2011).

In this research, a five-phase framework for sustainable supplier evaluation and order allocation process with multiple products multiple sourcing is presented. It comprises the supplier evaluation sub-model and the order allocation sub-model. A three layer architecture is proposed to support the development of an agent-based system. The proposed MAS concentrates on the automated transferring of information between manufacturer and its suppliers. Besides, we propose cloud-based workflow technology as a novel online requirement gathering tool in suppliers' organizations. The scope of the current paper is limited to presenting the proposed ABMS approach and the framework, system of agents, agents' description and behavior, protocol specifications and introducing the implementation tools. Using a numerical example from the medical device industry, the internal behavior of the supplier evaluation sub-model that utilizes an efficient Fuzzy Inference System (FIS) is demonstrated. The improvements and comprehensive implementation of the prototype of the proposed framework is being investigated and will be reported in further studies. The paper continues with Section 2 that presents the literature review. It follows by Section 3 that describes the proposed framework. In Section 4, system implementation steps are explained and illustrated. Finally, some remarks are concluded in Section 5.

2 LITERATURE REVIEW

Using agent technology, SC business decisions concerning order allocation, demand forecasting, pricing and workforce and plant investment, all functions with a time dimension, can be addressed (Lee and Kim 2008, Ghadimi and Heavey 2013). One of the important advantages that comes with applying agent technology is the capability to provide an approach to design a process automation system (Soroor et al. 2012). SC actors (buyer-seller dyad) and their corresponding agents in a simulation model play an important role in modeling supply chains as agent-based systems (Valluri and Croson 2005, Mishra, Kumar, and Chan 2012). This fact was strengthened and backed up by (Chatfield, Hayya, and Harrison 2007) as they mentioned SCs to be working as decentralized systems with entities which interact according to their roles and abilities inside organizational structures. These analogies naturally lead to the multi-agent approach being a possible way to represent SCs' complexities. Agent technology has been applied to tackle the problems in the manufacturing and scheduling as well (Lee, and Kim, 2008).

Supplier evaluation and selection comprises many tasks that are illustrated in Figure 1 (De Boer, Labro, and Morlacchi 2001). A generic process always starts with identifying the needs. Then, the main evaluation criteria, sub-criteria and the influencing factors need to be formulated based on the needs and type of the industry. Recently, due to social and environmental obligations and legislations, organizations are trying to incorporate sustainability TBL attributes into their supply and purchasing activities (Ghadimi et al 2012, Ghadimi et al. 2013). Accordingly, this research activity incorporates the TBL attributes in supplier evaluation and order allocation process. Information gathering comes next which is a very important task as it can affect the whole process if it is not conducted appropriately. Selecting the best assessment method and at the same time the most efficient one is the next step in evaluating the suppliers' performance. Finally, the evaluation and selection would be done based on the assessment results derived from the selected assessment methodology. In terms of traditional subjective selection methods, one of the most commonly used approaches is analytical modeling (Ho, Xu, and Dey 2010). However, SC as a whole and supplier selection and evaluation as one of its constituting elements deals with various uncertainty and dynamics so that it can be considered as a complex adaptive system. Effective handling of the dynamics and uncertainty of such systems is somehow impossible using the analytical models. This is due to their computational burden that mitigates against obtaining definite results in such a complex system, such as a SC.

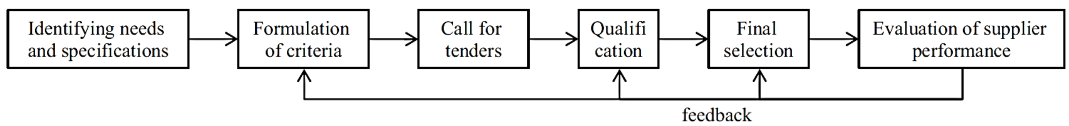

Figure 1: Supplier selection process (De Boer, Labro, and Morlacchi 2001).

A number of researchers has attempted to apply a model of the buyer-supplier relationships using the agent-based approach. The first attempt was in 2004 where Dzeng and Lin presented an agent-based system named C-Negotiators that helps a contractor and suppliers to negotiate via the Internet. This system mainly help contractor to select their appropriate suppliers through a parallel negotiation process. The embedded mathematical model in this system tries to maximize a payoff function jointly for suppliers and contractor which is optimized using Genetic Algorithms (GA). The evaluation criteria in this research are just limited to price and delivery. Valluri and Croson (2005) developed a system of agents consisting of a learner agent who learns to produce products based on their optimal level of quality. Besides, it also consists of a buyer agent where it handles the system of rewards and punishments. Reinforcement learning (RL) was utilized as the internal behavior of the learner agent. Their study is considered as one of the well-known and highly cited studies in this research domain. Soroor et al. (2012) investigated the supplier selection problem and developed an intelligent fuzzy algorithm to evaluate supplier bids without direct human intervention. In their proposed method, the supplier selection decision was implemented with the devised Fuzzy QFD technique within the Fuzzy AHP framework. Recently, Yu and Wong (2014) proposed a multi-product supplier selection model incorporating the synergy effect between products realized as a MAS. The TOPSIS based supplier pre-selection algorithm is established to evaluate suppliers based on predefined. JADE under Eclipse and MySQL was used for storing the relevant information and knowledge of suppliers, products within this research.

However, none of the above works considered the TBL attributes in their agent-based model. Besides, there is no research study that combines supplier evaluation and order allocation with the ABMS research domain. The main benefit of the proposed supplier evaluation and order allocation framework is to automate this process based on the information sharing concepts which is a baseline in the requirement gathering and the implementation stages. The actual contributions of this research are (i) using of an intelligent network of agents in the process of supplier evaluation and order allocation. (ii) applying simulation-based optimization approach in order to consider the uncertain environment of the supply chain (buyer-seller dyad) into the order allocation process which results in reducing the given complexity of the mathematical modeling optimization approaches. (iii) considering the sustainability TBL attributes in the process of supplier evaluation and incorporating them into the order allocation process. (iv) utilizing a structure manner of gathering and saving required information for evaluating and allocation orders to supplier using a proposed workflow management system.

3 THE PROPOSED MULTI-AGENT SUPPLIER EVALUATION AND ORDER ALLOCATION SYSTEM (MASOS) FRAMEWORK

The main objective of this research is to facilitate and automate the process of supplier evaluation and order allocation considering sustainability issues using agent technology approach. Intelligent agents as a part of distributed artificial intelligence can facilitate the activities that need group decision making. Considering MAS and ABMS in the domain of supplier evaluation and order allocation can make the whole process more automated as there are simulation replications along time periods which can capture and decrease the uncertain behaviors of the last two upstream actors of supply chain (manufacturer and supplier). Most of the agent-based supplier selection studies are about having a pool of potential suppliers and applying a method to select the most appropriate ones (Govindan et al. 2013). In those studies, the evaluation and selection is done just once and afterwards there is no guarantee that the selected suppliers are having the same appropriate performance comparing with the time that they were firstly evaluated and selected.

We proposed a five-phases agent-based framework for the supplier evaluation and order allocation process with multiple products multiple sourcing considering sustainability issues. Each phase of the MASOS is briefly described in this section and the agent-based realization of them are detailed in subsequent sections. (i) Problem formulation: determine the product(s) needed to be procured, and the corresponding procurement strategy. (ii) Criteria formulation: formulate the criteria used to measure the sustainability score of each supplier regarding the selected product, the criteria used to evaluate the suppliers in the supplier evaluation phase. (iii) Requirement gathering: collect all the possible and needed information for evaluating the suppliers and allocate orders to them in a structured manner. (iv) Supplier evaluation: obtain each sustainability dimension scores for each supplier using an efficient proposed methodology. These scores would be utilized in the order allocation phase. (v) Order allocation: the order allocation model will be constructed regarding the suppliers' score for each sustainability dimension in order to allocate the optimal order quantities to each supplier within the defined time periods using simulation replications.

The main advantage of the proposed Multi-Agent Supplier evaluation and Order allocation System (MASOS) framework is to provide new methods for faster gathering and sharing of data and information in the process of allocating orders among various selected suppliers and also sending/receiving the necessary commands to/from various sections of the networks in the shortest possible time. Besides, upon having more interactions between the suppliers and manufacturer regarding evaluation and allocation activities, it is more likely to have an increase in the quality of the finished products and complying with sustainability legislations and directives.

3.1 Supplier Evaluation and Order Allocation Models

In the proposed framework, the problem formulation phase is described by the purchasing company. The purchasing company will determine the product(s) required and the procurement strategy. Then, in the next phase the relevant criteria will be formulated based on the defined problem. The manufacturer will be asked to select their desirable criteria regarding the TBL attributes. The remaining three phases are accomplished by two sub-models: supplier evaluation sub-model and order allocation sub-model. These two sub-models work cooperatively to accomplish the procurement of the order quantity. The objectives of the two sub-models are described as follows:

- Supplier evaluation sub-model:
  - To determine the relative importance of these criteria and sub criteria by the decision maker's inside the purchasing company using Fuzzy Analytical Hierarchy Process (FAHP).
  - To obtain each supplier's performance score by the Fuzzy Inference System (FIS)-based evaluation algorithm.
- Order allocation sub-model:
  - To minimize the purchasing company's total cost.
  - To maximize the suppliers' sustainability performance according to their performance scores.
  - To allocate the optimal order quantities in each period of time based on the MOLP model by considering the suppliers' production capacity, manufacturer's storage capacity, manufacturer's demand for each period, demand and delivery constraints (using agent-based simulation optimization approach)

The first sub-model is explained and illustrated through a case study using an example from the medical device industry in Section 4. The detailed implementation of the second sub-model is beyond the scope of the current research study and is presented for future work. The structure of the agent-based structure of the proposed framework is presented in the next section.

3.2 Requirement gathering

In the developed framework, the data and information are gathered through utilization of a structured approach such as engineering workflow management which is a key focus for European manufacturing companies, however, issues such as time required to gather data, develop systems and integrate into current manufacturing environments presents obstacles for adoption (Daniels et al. 2013). An engineering workflow management system has been incorporated into the MASOS framework to tackle the third phase related to collect all the possible and needed information for evaluating the suppliers and allocate orders to them. The developed engineering workflow system would be running online through the use of cloud technology. Therefore, the MASOS agents can directly retrieve the online information gathered from the suppliers which can be considered as an important advantage for the developed framework. Besides, It is worth to mention that using cloud-based workflow management tool enhances the process of information sharing among the buyer and its suppliers.

3.3 MASOS architecture

The architecture of the agent-based system supporting the proposed supplier evaluation and order allocation model is depicted in Figure 2.

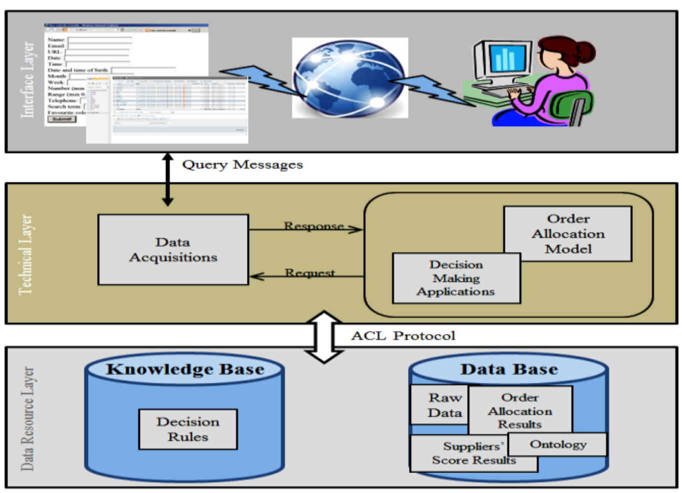

Figure 2: Three layers system architecture.

It contains three layers, namely, Interface Layer, Technical Layer and Data Resources Layer. In the Interface Layer, a user interface will be developed using a workflow management tool in order to gather the required information for the specified criteria regarding three dimensions of sustainability (environmental, economic and social) and also for the data needed for implementing the order allocation model such as purchasing cost, transportation cost, ordering cost and etc. The Data Resources Layer is composed of (i) product knowledge data base where the specifications and requirement of the required products such as delivery time, price and etc. are stored, (ii) supplier knowledge data base where the data sent by each supplier regarding the defined evaluation criteria are stored and finally, (iii) results data base where the obtained results from various replications of the system for each period are kept including the optimal order quantities and each supplier's performance score. The Technical Layer mostly communicates with the other two layers for retrieving the required information and accomplish the supplier evaluation and order allocation process.

3.4 Agents in MASOS

The functions of the MASOS are realized by the proposed MAS. In this architecture, we define four types of agents: Manufacturer Agent (MA), Supplier Agent (SA), Decision Maker Agent (DMA) and Order Allocator Agent (OAA). Agents involved in the evaluation sub-model are the SAs, MA and DMA; agents involving in the order allocation sub-model are SAs, MA and OAA. The functions and responsibilities of these agents are defined and described in Table 1.

Table 1: The responsibility table.

Agent	Responsibilities	Agent	Responsibilities
MA	- Initiate the evaluation and order allocation processes. - Send the supplier evaluation request to DMA and Receive - Request the supplier evaluation related data from the SA and send the requested data to DMA. - Send the order allocation request to OAA. - Request the order allocation related data from the SA and send the requested data to OAA. - Receive the supplier evaluation and the order allocation results from DMA and OAA. - Send the evaluation and order allocation results to SAs.	SA	- Obtain the required data for supplier evaluation from SQL server database and send the obtained data to MA. - Inform MA upon receiving new data from the suppliers in order to initiate simulation replication. - Accept the SA evaluation and order quantities results from MA. - Save the results into the SQL server database.
OAA	- Request and accept the performance evaluation indices from the MA. - Request and accept the information related to each supplier from the MA. - Determine the optimal order quantities by the order allocation model and solution approach - Inform the results to each MA.	DMA	- Receive the evaluation request from MA. - Request and receive the evaluation data from MA. - Evaluate the suppliers by the proposed supplier evaluation algorithm - Inform the evaluation results to the MA.

3.5 Analysis and design MASOS

Supplier selection is basically the buyer-seller relationship in a typical supply chain. The purchasing company is the buyer and the suppliers are sellers. In the supplier selection process, there is one buyer (purchasing company) and multiple sellers (suppliers), and the supplier selection process can be considered as a one-to-many negotiation. In this research, the proposed supplier evaluation and order allocation model is modelled as a distributed MAS. We performed a literature survey on the development methodologies of MASs (Wooldridge, Jennings, and Kinny 2000). These methodologies are generic in nature and try to adapt object-oriented approaches to agent-based design (Nikraz, Caire, and Bahri 2006).

The proposed methodology in Nikraz, Caire, and Bahri (2006) is applied. This methodology is generic in the analysis phase. But, it is fully complied with the popular FIPA-compliant JADE platform in the design phase which can be considered as a genuine advantage. Throughout the analysis phase, the problem is clarified without any concerns about the solution. In this phase, agent types were identified and refined by applying a number of considerations. These considerations are (i) support: which is related to check how, when and where is the required information retrieved/stored. (ii) discovery: which defines how each agent is going to find the other agents. Naming convention and yellow pages mechanism are two easily implementable approaches to solve the agent discovery problem. Each of these approaches has their own benefits and limitations. However, the second approach completely maps to the directory facilitator agent provided by JADE. (iii) management and monitoring: where some agents need to be tracked or created on demand (Nikraz, Caire, and Bahri 2006). In the MAS, autonomous agents are established to represent various parties and functions of the supplier evaluation and order allocation process.

The agent diagram for MASOS is modeled and shown in Figure3 In this diagram, the actual agent types are represented by clouds. In each supplier company, one person must key in the required information for every simulation replication that takes place for each period. The length of each period varies regarding the type of the industry where the proposed framework is being implemented (every week, every month and etc.).

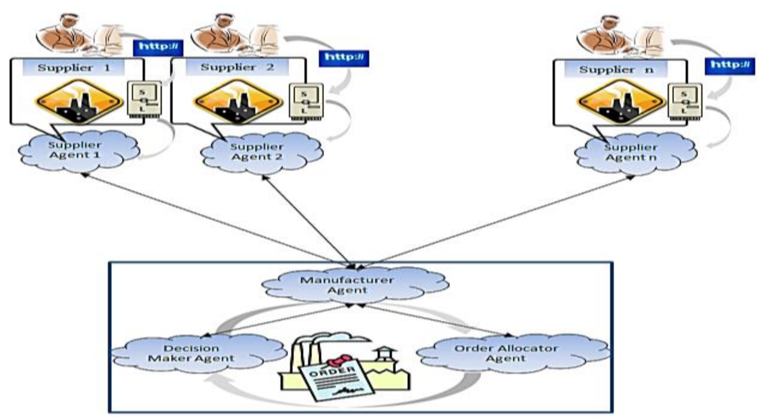

Figure 3: Agent diagram.

Using a well-defined workflow system of each supplier company, a structured method of requirement gathering is provided for these companies. The workflow system stores the input data into a SQL server within a manufacturer's organization. The transformation of these data is possible using the cloud technology that workflow management system tool can provide.

3.6 Agent communication

Agents mostly communicate through a form of interaction that specifies their external relationships with each other. In current study, the identified agents in the MASOS communicate with each other by sending messages from sender to receiver. The content of the message can be encoded by sender and decoded by receiver. In current study, FIPA Agent Communication specifications will be utilized in order to deal with Agent Communication Language (ACL) messages, message exchange interaction protocols and content language representations. FIPA SL content language which is a human-readable string-encoded content language will be utilized in implementing the MASOS. Two interaction protocols which are supplier evaluation protocol and order allocation protocol are proposed to support the supplier evaluation and order allocation considering sustainability issues process. These protocols are implementable by the FIPA interaction protocols which have been provided by the JADE platform.

3.6.1 Supplier evaluation protocol

The supplier evaluation protocol governs the interaction of agents supporting the supplier evaluation sub-model. It is used to evaluate the suppliers for the multiple required products in order to allocate order quantities to them based on the TBL attributes. This protocol is depicted in Figure 4.

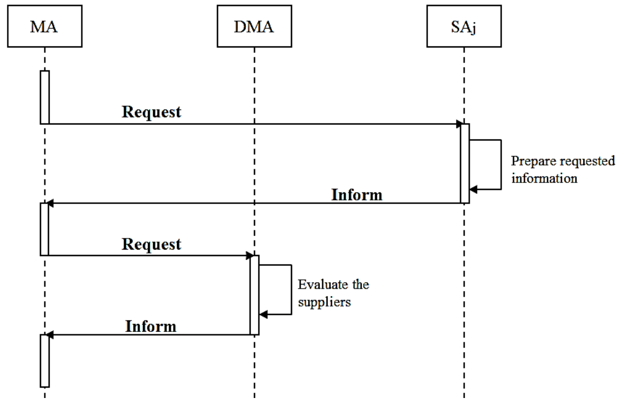

Figure 4: Supplier evaluation protocol.

In JADE, this protocol can be implemented by the FIPA Request Interaction Protocol (IP) and FIPA Query IP (Query-ref). As shown in Figure 4, the MA *requests* information from the SA_j to initiate the agents' communication. The SA_j receives this request, and then *inform* information to the MA. The acquired information from the database containing the sustainability influencing factors values needed for evaluating the suppliers is then sent to the DMA together with the *request* for evaluating the suppliers from the MA. The DMA then executes the proposed FIS-based supplier evaluation algorithm introduced in Section 4.1 to evaluate the suppliers. Then, the DMA *informs* the results to the MA. The results contain each supplier's performance index that will be considered as an input for implementing the order allocation mathematical model.

3.6.2 Order allocation protocol

The order allocation protocol governs the interactions of agents supporting allocating optimal order quantities to the suppliers currently involved with the manufacturer. In this protocol, the suppliers will submit their information needed by the order allocation model embedded in OAA such as price, production capacity and etc. The suppliers know that submitting higher prices for the requested products and also low performance will lead to be allocated less order quantities in each period of time. Initially, the MA *requests* the SA_j to prepare the information required for implementing the order allocation model. Then, the SA_j *inform* this information to the MA. Consequently, the MA *requests* the OAA to run the order allocation multi-objective model in order to obtain the optimal order quantities for each supplier.

4 IMPLEMENTATION OF AGENT-BASED SUPPLIER EVALUATION AND ORDER ALLOCATION SYSTEM

The MASOS prototype will be implemented in the JADE open system development platform. A platform is composed of one or more containers. Containers can be executed on different hosts thus achieving a distributed platform. One host may hold several agent containers concurrently. Each container can contain zero or more agents. Agents live in containers which are the Java process that provides the JADE run-time and all the services needed for hosting and executing agents. There is a special container, called the main container, which represents the bootstrap point of a platform: it is the first container to be launched and all other containers must be joined to a main container by registering with it. When the main-container is launched, two special agents are automatically instantiated and started by JADE: the Agent

Management System (AMS) is the agent that supervises the entire platform; the Directory Facilitator (DF) is the agent that implements the yellow pages service, used by any agent wishing to register its services or search for other available services.

The MASOS is also composed of agent containers that can be distributed in different hosts over the network. Besides the AMS and DF, functioning agents defined in the proposed system could be located in various containers and hosts. In this research, the purchasing company holds the main-container and several other containers. The suppliers hold their own agent containers which must connect to the main-container. Concerning the agents owned by the purchasing company, there is one instance of the MA, DMA and OAA. As shown in Figure 5, for simplification, these agents nest in the same host as AMS and DF, and in a different container. The suppliers only possess the instance of SA in their containers. Agents of the MASOS realize the evaluation and order allocation process through message transportation. Development tools involved in implementing the MASOS are JADE, Eclipse, RunMyProcess (RMP) as the workflow management tool for requirement gathering and MySQL as the database system.

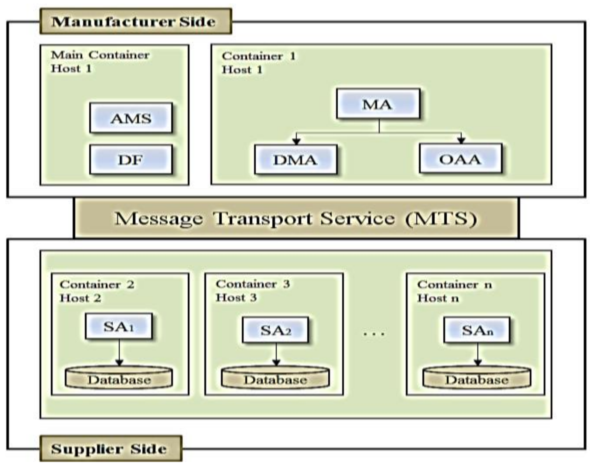

Figure 5: Configuration of the MASOS in JADE.

4.1 Supplier evaluation sub-model implementation

Owing to the space limitations, we refer the readers to look for the details of the proposed methodology and preliminary notations of the utilized tools in our previous publications (Ghadimi et al. 2012, Azadnia et al. 2013). However, the summary of the proposed methodology for supplier evaluation that is incorporated in the MASOS framework and will be implemented by the DMA is presented in the following together with its recent application on a case study in medical device industry.

Step 1: Identify potential suppliers to evaluate.
Step 2: Select suitable sub-criteria and influencing factors.
Step 3: Weighting the sub criteria and main criteria using FAHP.
Step 4: Requirement gathering.
Step 5: Implement FIS for quantifying the gathered requirements.
Step 6: Suppliers rankings.

A case study of a medical device industry is presented to illustrate the internal behavior of the DMA. Through this case study, it is explained how the DMA will be cooperating with other agents in the MASOS. Company XYZ is a manufacturer of medical devices for hospitals and health care organizations. It is located in Shannon, Ireland. The XYZ manufactures under guidelines set out by the US Food and Drug Administration (FDA) in relation to medical device development and production.

Recently, the XYZ company initiated a new production line for the manufacture of a new type of product. For sourcing one component of this product, three suppliers were identified by the production team of the company. All of these three suppliers are operating under FDA guidelines. The most important and time consuming part of this research was to identify the appropriate evaluation sub criteria that was done after many meetings and discussions (Figure 7). It should be noted that many of these criteria are specifically related to the medical device sector.

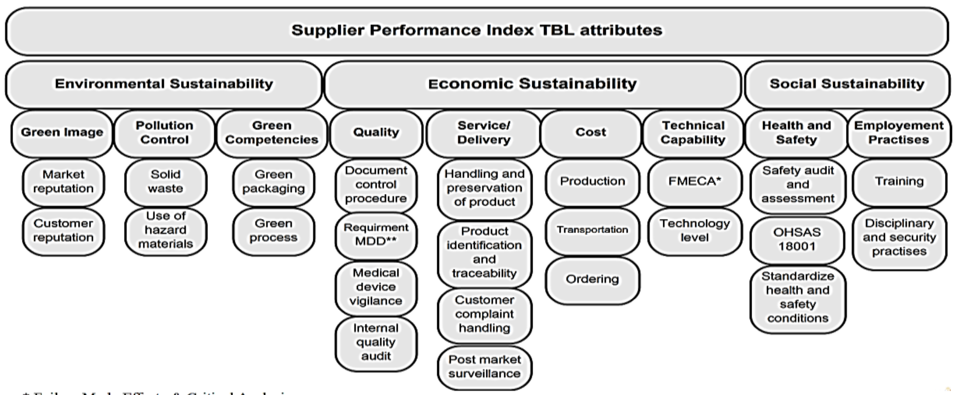

Figure 7: Supplier evaluation sub criteria and influencing factors.

Afterwards, it was decided to consider equal weighting for the defined sub criteria and main sustainability dimensions. In the third phase of the MASOS framework, a workflow will be developed for the suppliers in order to gather the required information related to these sub criteria and influencing factors. The cloud technology involved in the workflow management tool will extent the functionalities of the proposed framework (MASOS) in allowing better information sharing among manufacturing company and its suppliers which obviously can help to decrease the uncertainty involved in the process. The SAs will then process the information and store them in their appropriate data base in the manufacturing company's MySQL database. This process will replicate every period defined by the manufacturer as it can be easily implemented to be setup in the suppliers' company.

4.2 Utilized Fuzzy Inference System (FIS)

In the next step, the MA agent will be notified of the newly stored information in the database and will ask for that information and will send it to the DMA to initiate the supplier evaluation process. The DMA then transforms these crisp data into grades of membership for linguistic terms of fuzzy sets. After determining the grades of membership, the target range or reference value is to be set for each input variable. This value indicates the minimum and maximum values of the input variable. The selection of reference values is usually based on the national and local policy or may be set by the organization or manufacturer to meet their objectives. Constructing the input variables' membership function is based on these reference values. Then, the linguistic value of zero to one (0 to 1) is selected as a reference value for constructing the output membership function. After constructing the membership functions for input and output variables, fuzzy rule base system will be constructed based on the decision makers' knowledge inside the organization. These decision makers can be the company owner, chief executive officer, general manager, system manager or a combination of these. Fuzzy inference comes after constructing the rules. In this part, the result of each rule is generated as fuzzified inputs and goes through an inference system. The output of the fuzzy inference system is the input for the defuzzification process (Ghadimi et al. 2012; Azadnia et al. 2013; Ghadimi and Heavey 2014).

Table 2 tabulates the evaluation results of the three suppliers together with their sustainability performance index. After obtaining these result, the DMA will inform the MA and the MA will send them to the SAs to be stored in their respective row in the database. These results will be then retrieved by the MA to request the OAA to run the optimization order allocation model in order to obtain the optimal order quantities. The SAs will be informed of these results. The process stops in this step and the simulation replication will be considered as accomplished until new information arrival in next period or any changes in the input data due to various reasons such as sudden change in material costs, market demand fluctuation, seasonality and etc. All of these simulation scenarios are intended to be considered in our future prototypically realization of the MASOS in order to validate and prove its entire efficiency and functionalities.

Table 2: Supplier evaluation results together with their sustainability performance index.

	Supplier 1	Supplier 2	Supplier 3
Environmental sustainability	**0.42**	**0.64**	**0.75**
Green image	0.25	0.75	0.75
Pollution control	0.52	0.41	0.77
Green competencies	0.50	0.75	0.75
Economic sustainability	**0.61**	**0.44**	**0.64**
Quality	0.69	0.75	0.56
Delivery/Service	0.75	0.25	0.50
Cost	0.50	0.25	0.75
Technical capability	0.50	0.50	0.75
Social sustainability	**0.46**	**0.70**	**0.72**
Health and safety	0.50	0.75	0.76
Employment practices	0.43	0.65	0.68
Supplier performance index	**0.45**	**0.59**	**0.71**

5 CONCLUSION

This paper presented a multi-agent sustainable/green supplier evaluation and order allocation framework namely, MASOS. The MASOS consists of two main sub-models. The first sub-model handles the process of supplier evaluation based on the TBL attributes and the second one deals with the order allocation process. The MASOS framework is realized using agent technology and the state-of-the-art cloud computing technology in order to facilitate and automate the buyer-supplier relationships regarding the supplier evaluation and order allocation process. In this research study, the functionality of the supplier evaluation sub-model was demonstrated using a case study from the medical device industry using an efficient FIS approach. The MASOS framework is constructed of various autonomous agents. Each of these agents takes part in each phase of the MASOS. They have their own internal objective and behavior and pursue the overall objective of the whole framework. The presented results of the supplier evaluation sub-model explained how various agents can cooperate together in the proposed agent-based model. The improvements and comprehensive implementation of the prototype of the MASOS is being investigated and will be reported in further studies.

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