An Analysis of Methodologies for Agent-Based Modeling for E-Manufacturing Systems in South Africa

Mncedisi Trinity Dewa, Stephen Matope, Lungile Nyanga, Andre Francois van Der Merwe and Talon Garikayi

Abstract— In order to remain competitive, South African manufacturing firms should adopt E-Manufacturing Systems. These solutions enable the sharing of resources and skills over a collaborative manufacturing network platform with the aid of Multi Agent Systems (MAS). However the success of MAS design is based on the selection of the relevant structured methodologies. This paper presents the different possible methodologies used in the design of MAS for an e-manufacturing system. An analysis of the strengths and weaknesses of each methodology reviewed was presented so as to establish the best design methodology for MAS systems which support e-manufacturing models in the South African industry. A survey of current manufacturing methods used was done; recommendations and conclusions were drawn basing on the applicability of the proposed method to aid the development process. The success of this research created a backbone for the establishment of an e-manufacturing systems development framework.

Keywords— E-Manufacturing, Intelligent agents, Multi agent Systems,

I. Introduction

THE new paradigm of agent-oriented analysis and design has stirred so much interest in the research community and as a result several different methodologies have been proposed on how to architect MAS. The availability of a wide variety of methods and approaches for building MAS poses a challenge for MAS developers on the selection of the most appropriate method to use. The paper presents a survey of the most common methodologies for building MAS so as to select the best method which suits the development of e-manufacturing systems for South African industrial clusters. The organization of the paper is as follows: first we look at e-manufacturing adoption in South Africa, we then discuss the different approaches for current methodologies used in MAS analysis, design and implementation and lastly we make a comparison of these methodologies, considering their strengths, limitations and applications so as to select the best methodology for building of MAS for the South African e-manufacturing model.

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II. E-Manufacturing

A. Definition

E-manufacturing is concerned with the utilization of wireless technologies, e-business and the internet to facilitate seamless information transfer during manufacturing [1]. According to McClellan [2], an e-manufacturing strategy is the technology key which unlocks information transparency throughout the entire supply chain by ensuring e-business processes such as job shop production or reliability-centered maintenance are implemented by generating guidelines. The internet and wireless technologies have enabled manufacturing and the business worlds to enter into the era of e-manufacturing [3].

B. Components

The seamless availability of information is the life-blood of any organization. Manufacturing information enables stakeholder and operations personnel to make decisions quickly and respond flexibly to changes occurring in the manufacturing environment. E-manufacturing eliminates data bottlenecks that can occur in conventional enterprise solutions by enabling information exchange [4].

The components of an e-manufacturing system are shown in Figure 1 in a model representing e-manufacturing system architecture successfully used in Taiwan. The model has four core components: manufacturing execution system (MES), supply chain (SC), equipment engineering system (EES), and Engineering Chain (EC).

C. Adoption by South African Industry

The world has become a global market with customers now able to get their needs met with aid of e-commerce where trade barriers have been removed. With the rapid growth in manufacturing technologies and the internet, most manufacturing firms are now adopting agile manufacturing policies to improve their productivity, responsiveness and customer service. In response to these overwhelming trends, a lot of research is being conducted on the possibility of South African manufacturing firms implementing e-manufacturing systems. These systems allow manufacturing firms to position themselves in a competitive manner by allowing the sharing of information and resources over a collaborative network. To achieve this worthwhile goal, multi-agent systems have been recognized as one of the technologies that would facilitate the implementation of e-manufacturing by providing manufacturing enterprises with the capabilities of flexibility, robustness and adaptability to the rapid changes that occur in the manufacturing environment [6]. By implementing e-manufacturing strategies, the potential benefits South African manufacturing firms will enjoy include a cycle time reduction, increase in quality levels, inventory cost minimization, forecast accuracy increase, improvement in delivery performance, reduction in work–in-progress and a significant reduction in paperwork usage.

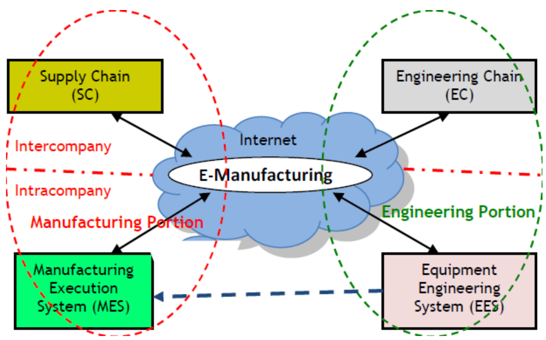

Fig. 1 Components for the advanced e-manufacturing model [5]

III. MULTI AGENT SYSTEMS

A. Definitions

An agent is a software entity located within an environment capable of autonomous behavior to achieve its design objectives and goals [7]. However, Monostori [8] defined an agent as:

"A software object that mimics the role of a competent personal assistant to perform some specific task on behalf of a user, intelligently or not, independently or with little guidance."

Intelligent agents are software constructs which are autonomous, problem solving, and computational structures with an inherent capability of effective operation in dynamic and open environments. It is a computational system that is situated in a dynamic environment and is capable of autonomous, intelligent behavior. A Multi Agent System is a system that contains a set of agents that interact with communications protocols and are able to act on their environment. Different agents have different spheres of influence, in the sense that they have control (or at least can influence) on different parts of the environment. These spheres of influence may overlap in some cases [9].

B. Types of agents

Different types of agents have been used in several domains and applications. Agents can be classified as [10]:

- Reactive agents which perceive changes in the environment and respond on a stimulus-action mode to act on the environment.
- Rational agents are agents that act on achieving the tasks they were assigned to them so as to maximize specific measures of performance or its design objectives.
- Cognitive agents are mainly characterized by a symbolic representation of knowledge and mental concepts. Their structure depicts a partial representation of the environment with explicit goals. They are capable of planning their behavior, remembering their past, communicating by sending messages and negotiating.
- Intentional or BDI (Belief, Desire and Intention) agents are intelligent agent that applies principles of human behavior or flexible behavior in their actions. Their deliberate actions are based on defined beliefs, desires and intentions.
- Adaptive agents adapt to any changes that the environment can have. They are very intelligent and are capable of changing their objectives and knowledge base when necessary.
- Communicative agents are social agents used to communicate information around them. This information can be made of their reasoning patterns as it may be transmitted by other agents.

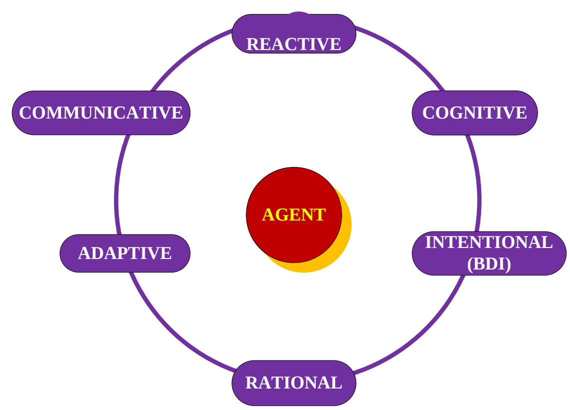

Fig. 2 Types of agents [10]

C. Organization

The overall operation of a multi-agent system is affected by the network topology of the individual agents. The arrangement of the individual agents depends on the nature of the problem being solved and the application domain in which the solution will be implemented. The organization determines the "sphere" of the activity of agents, as well as their potential interactions (see Figure 3). [9]

In manufacturing practice, most operations follow a hierarchical order with well structured ranks of authority. Due to this, many variants of organizational models and cooperation patterns have appeared throughout the history of manufacturing systems. However, with the emergence of artificial intelligence and computer science, manufacturing applications seek for more robust, adaptable, fault-tolerant, decentralized and open organizational structures.

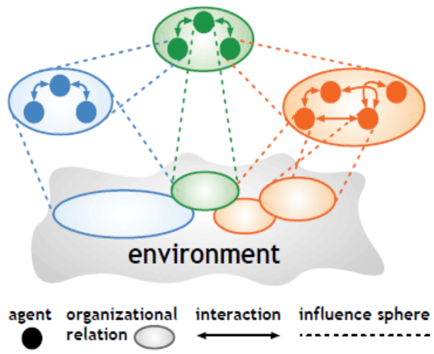

Fig. 3 Generic scheme for a multi agent system [11]

D. Proposed MAS for South African E-Manufacturing

To enable South African manufacturing firms in the tooling industry of the Western Cape Province to join in collaborative networks which facilitate an increase in manufacturing resource utilization, an E-manufacturing framework was proposed by Nyanga [12]. The framework consists of a multi agent system (see Figure 4) which contains functional intelligent agents managed and supervised by a Managing Agent through the internet.

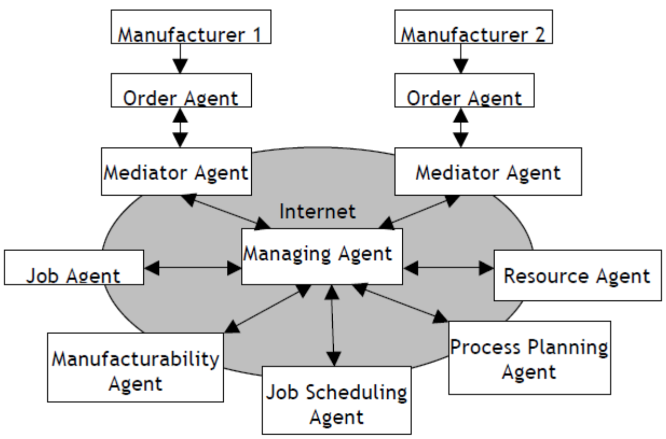

Fig. 4 Multi Agent System framework [12]

The rational agents can be installed on different computers and distributed in different geographical places. The architecture of the system follows a star network topology. The goal of this paper is to select the best methodology for developing the proposed multi agent system. The MAS's main environment and form of communication was proposed to be the internet making the architecture open and distributed. The selected method must be suitable for design of such applications.

IV. Methodologies For MAS Design

In recent times a great number of agent-oriented modeling techniques and methodologies have been proposed. A methodology by definition is a structured sequence of discrete steps or guidelines which facilitate the process of analyzing, designing and implementing a system [13]. However, Blanes [14] alludes to the fact that 79% of the current methodologies for MAS development have been adapted from other paradigms such as object-orientation, social abstraction, knowledge engineering and formal design. Each approach has its own set of methodologies supporting the paradigm's development concepts. These paradigms can be classified into four distinct approaches.

Social-level abstractions are based on organizational paradigm which is characterized by a clear focus on capturing the hierarchical structure of agent, groups. Examples of methodologies under this group are GAIA [15], SODA [16], Cassiopeia [17], AALAADIN [18], and EXPAND [19]. Object-orientation approaches are based on the background derived from object-oriented languages which emphasize the concepts of abstraction, polymorphism, inheritance and encapsulation. Examples of methodologies under this group are KGR [20], MaSE [21], MASSIVE [22], AOAD [23] and MASB [24]. Knowledge engineering abstractions are characterized by an emphasis on the discovery, attainment and modeling of knowledge to be used by the individual agent of a software system. The two best examples of such methods currently available are CoMoMAS [25] and MAS-CommonKADS [26]. Formal approaches focus on the specification and verification of agent systems. Examples of methodologies under this group are DESIRE [27] and axiomatic approaches [28].

The availability of numerous methodologies for analyzing and designing Multi-Agent Systems (MAS) makes it difficult for MAS-developers to compare the available MAS development methodologies and decide on the most appropriate methodology to use in a specific application. Unfortunately, not all methodologies are suitable for the analysis, design and development of MAS for an e-manufacturing system.

Since a majority manufacturing applications are developed using the hierarchical structure were organization is key, we focus on the most commonly used, well defined methodologies which support the organizational structure paradigm based on the Social level abstractions. In this paper, we chose to compare the GAIA [15], SODA [16] and EXPAND [19] methodologies because all the three methods have an emphasis on social level abstractions. They are all well-developed, practical, and provide specific process or phases in system analysis and design. The Cassiopeia [17] and AALAADIN [18] methods were not included in the analysis because they are not well developed and they have a limited application.

V. Methodology Overview

A. GAIA ("Generic Architecture for Information Availability) [15]

The GAIA methodology is generic in nature and applicable to a wide range of applications. The method is founded on the perception of a multi-agent system as a computational organization consisting of various interacting roles. Agents form teams as they belong to a unique organization. The design steps are comprehensive in that both individual agents and teams of relating agents can be modeled. The analysis and design stages are explicitly distinguished as shown in Figure 5.

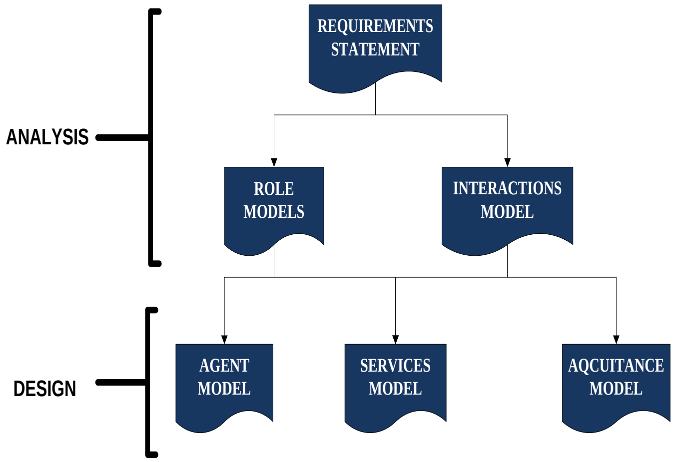

Fig. 5 GAIA Model structure [15]

In the analysis stage, the organization model is separated into two further models: the role model and the interaction model. The role model identifies the key roles in the system. These roles are characterized by a defined description of rights and functionalities. The interaction model represents the relationships between various roles in the organization. Protocol definitions for each type of inter-role interaction are clearly made. A protocol is viewed as an organization's pattern of interaction.

In the design stage, the analysis models are translated into sufficiently low-level abstractions in order to implement agents. Three models are generated at this stage which is the agent model, the services model and the acquaintance model. The agent model identifies the agent types that will make up the system. The services model identifies the main services that are required to realize the agent's role and the acquaintance model documents the lines of communication between the different agents.

B. SODA ("Societies in Open and Distributed Agent spaces) [16]

SODA is a methodology for the analysis and design of Internet-based applications based on the notion of task. The method emphasizes inter-agent issues like development of societies and their environment for multi agent systems. Coordination models are taken as the sources for the abstractions and mechanisms required to create societies. Social rules are designed as coordination laws, and society infrastructures are built upon coordination system. The agent environment is explicitly taken into account.

During the analysis phase of the SODA methodology, three distinct models which are the role model, resource model and the interaction model are developed. In the role model, the tasks to be achieved are modeled in terms of the associated roles and groups. The resource model environment is modeled in terms of the available services. The interaction model combines roles, groups and resources modeled in terms of interaction protocols.

During the design phase, the abstract models derived from the analysis phase are further developed which can be mapped one to one on to the actual components of the final system. The design phase defines three models. Firstly, the agent model represents the individual and social roles mapped from agent classes. The society model is designed around the coordination media, which embody the interaction rules of its groups in terms of coordination rules. In the environment model, resources are mapped onto infrastructure classes which represent the services to be provided by each infrastructure component, and its interfaces.

C. EXPAND ("Expectation-oriented analysis and design") [19]

EXPAND methodology emphasizes the aspect of agent autonomy. The expectations held by individual agents are defined as first-order abstraction. The designed agents are allowed a maximum degree of autonomy. The system level expectations are a key modeling abstraction during the analysis and design stage. The EXPAND analysis and design can be divided into four specific phases which can be combined into a single process model. These phases are:

a. Model system level
b. Derive expectation structures
c. Monitoring of system operation
d. Refining of expectation structures.

VI. METHODOLOGY COMPARISON

A. Advantages and shortcomings of the GAIA Methodology

The strengths of the GAIA methodology lie in the fact that it is a well developed methodology with a clear distinction made between the analysis stage and the design stage. Since it is based on the organizational paradigm, it is well suited for the development of manufacturing applications. Finally, the method employs responsibilities as an abstraction used to decompose the structure of a role.

However, the method does not explicitly take the environment that agents are situated in into account and does not suit well open systems. GAIA cannot easily deal with the design of self-interested agents and does not allow such a great deal of autonomy for agents.

B. Advantages and shortcomings of the SODA Methodology

The SODA methodology is an extension of the GAIA method which is based on the concept of coordination models known from the area of standard coordination languages. It is similar to GAIA in that it is also a well developed methodology with a clear distinction made between the analysis phase and the design phase. Since it is based on the organizational paradigm, it is also well suited for the development of manufacturing applications. By exploiting suitable coordination models as a basis for engineering of societies to be designed around suitably designed coordination media, and social rules to be designed and enforced in terms of coordination rules, it solves the problems of GAIA which does not suit well open systems and cannot deal with self interested agents. Furthermore, SODA explicitly takes the environment that agents are situated in into account and provide engineers with specific abstractions and procedures for the design of agent infrastructures. The method employs responsibilities as an abstraction used to decompose the structure of a role.

However, although SODA has better features than GAIA in some aspects, it not only means that SODA is better than GAIA. SODA is a methodology utilized only for internet-based multi agent system while GAIA serves a wide range of multi-agent systems. On the other hand, SODA is as well developed as GAIA. The analysis and design process of SODA is more specific and clear. The method does not allow a great degree of autonomy.

C. Advantages and shortcomings of the EXPAND Methodology

EXPAND is a well developed methodology with a clear distinction made between the analysis phase and the design phase. Since it is based on the organizational paradigm, it is well suited for the development of manufacturing applications. The method allows a great deal of autonomy and restricts behavior only if necessary. The method employs the social-level expectation structure to fulfill the common goal of the system.

However, the method does not make a clear distinction between the analysis and design stages, proposing instead a flexible and adequate incremental analysis and design process which exploits the importance of the expectation level in open and autonomous agent based software systems explicitly take the environment that agents are situated in into account and does not suit well open systems.

Table 1 below summarizes the feature comparisons between the three methodologies.

TABLE I
METHODOLOGY COMPARISONS

Property	GAIA	SODA	EXPAND
Application Domain	Wide	Specific – Internet	Wide
Environment Modeling	No	Yes	No
Suitability for manufacturing applications	Adequate	Highly suitable	Unsuitable
Agent Autonomy	Low	Low	Very High
Distinction between analysis and design	Clear	Clear	No distinction
Construction process	Well developed	Partially developed	Partially developed

VII. PROPOSED METHODOLOGY

Based on the above comparison analysis, the SODA methodology is selected as the best methodology for developing e-manufacturing systems for the South African framework. This is because the methodology supports the development of multi agent systems in an open distributed environment. The proposed E-manufacturing framework is an internet based system hence it requires the SODA methodology.

VIII. CONCLUSION AND FUTURE WORK

The purpose of this paper is to select the best methodology for the analysis, design and development of a multi agent system which supports the e-manufacturing framework for South African manufacturers. The SODA methodology was selected as the best methodology to be adopted in the analysis and design stage.

In the future, we would like to use the SODA methodology to design and implement the multi agent system. The e-manufacturing will be further implemented using the Java Agent Development platform (JADE). This will help us to validate the efficacy of our proposed approach and lead us to consider it as a generic approach which can be adopted by every type of e-manufacturing system.

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