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# Intelligent Optimisation Agents in Supply Networks

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## Abstract

This paper describes a model of intelligent supply network that improves efficiency within the supply chain. We argue that intelligence creates efficiency and results in chain optimisation. In particular, intelligent agents technology is used to optimise performance of a beverage logistics network. Optimisation agents can help solve specific problems of supply network: reduce inventories and lessen bullwhip effect, improve communication, and enable chain coordination without adverse risk sharing. We model the beer supply network to demonstrate that products can acquire intelligence to direct themselves throughout the distribution network. Further, they gain a capability to be purchased and sold while in transit. Overviews of the supporting technologies that make intelligent supply network a reality are fully discussed. In particular, optimisation agents have the characteristics of autonomous action, being proactive, reactive, and able to communicate. We demonstrate that agents enhance the flexibility, information visibility, and efficiency of the supply chain management. Suggestions and recommendations for further research are provided.

## 1. Introduction

This paper presents the design of a new intelligent software system that integrates information systems developed for relationships between enterprises and the final consumer (Business to Consumer or B2C) and between suppliers (Business to Business or B2B). The proposed theoretical model uses Agent Technology and will assist both the producing firm and the customer to look automatically for an increase in the data exchange rate.

Agent technology has successfully been used in the past for in managing business processes, as described in ADEPT (Advanced Decision Environment for Process Tasks) from Jennings [10]. Based on the functionality of decision making from the company managers, the business process involves a combination of judgement and information from marketing, sales, research, development, and manufacturing and finance departments. Ideally all relevant information should be brought together before judgement is exercised. The ADEPT solves problems related to this process by

viewing it as a community of negotiating, service-providing agents. Each agent represents a distinct role or department and is capable of providing one or more services.

Within this paper the term 'agent' corresponds to the software problem-solving entities, which are situated in a particular environment, with specified functions, in order to process the inputs received related to the problem domain. The agents have the ability to control their internal state and their behaviour, to exhibit flexible problem-solving techniques in pursuit of their design objectives. The intelligent agent software system is designed to fulfil the specific purpose of analysing the information about the customers that is available currently at the retailers' databases.

Usually each software agent is a different specialist, able to accomplish certain tasks, thus providing co-operative members in a society. In this work, the scenario of knowledge co-operation on our study based on [10] will illustrate how certain components (i.e. supply agents) can be monitored from a multi-agent software system, by using intelligent specialized software agents, which will simulate the procedure of data analysis to extract useful information for the relationships between commercial partners [19]. The key aspects of this work, based on the previous research in the field [4], are:

- The identification of possible market relationships has been mapped to a 'communication' problem where different kinds of agents seek to exchange messages to satisfy and interpret data on an on-line basis.
- The agents are autonomous entities and they either work on their own or co-operate with others.
- Every aspect of the scheduling process (from initial data acquisition to the relationships' interpretation) must be available to the user, in order to understand the internal process of the software.

This study illustrates how agent technology can be used to solve real supply chain inefficiencies and optimise the logistics network. For instance, we explain how companies can use agent technology to collect data from retailers, group them into meaningful categories, and then perform different functions. As a result, the distribution chain can be managed more efficiently. Intelligent agents also make available timely data to inventory management resulting in reducing stocks and

tied capital. Intelligent agents are adoptive to changes so they are valuable in a dynamic environment where new products or partners have entered into the supply network. This flexibility gives agent technology a relative advantage which, for pioneer companies, can be a competitive advantage. The study concludes with recommendations and directions for further research.

The following sections of this paper describe intelligent agent technology, and discuss the need to re-engineer the supply network in association of technical needs and the solution of the agent-based information system is analysed. chain optimisation & re-engineering. A multi-agent architecture is described at a subsequent section and the paper concludes with recommendations and directions for future research.

## 2. Intelligent Agent Technology

*“An intelligent agent is an encapsulated computer system that is situated in some environment, and that is capable of flexible and autonomous action in that environment in order to meet its design objectives”* [22]. Agent technology has successfully been used in the past for in managing business processes, as described in ADEPT (Advanced Decision Environment for Process Tasks) [10]. Based on the functionality of decision making from the company managers, the business process involves a combination of judgment and information from marketing, sales, research, development, and manufacturing and finance departments. Ideally all relevant information should be brought together before judgment is exercised. The ADEPT solves problems related to this process by viewing it as a community of negotiating, service-providing agents. Each agent represents a distinct role or department and is capable of providing one or more services.

Within this paper the term 'agent' corresponds to the software problem-solving entities, which are situated in a particular environment, with specified functions, in order to process the inputs received related to the problem domain. The agents have the ability to control their internal state and their behaviour, to exhibit flexible problem-solving techniques in pursuit of their design objectives. The intelligent agent software system is designed to fulfil the specific purpose of analysing the information about the customers that is available currently at the retailers' databases.

In a more general way as in [22], the term 'agent' can be used, as a software-based computer system, which has the properties:

- *Autonomy*: It means simply that an agent is a computer system, which is situated in some environment, and it is able to act without the intervention of humans (or other agents), and should have control over its own actions and internal state and have some kind of control over their actions and internal state.

- *Social ability*: Agents can interact with other agents (or humans) via agent communication language (ACL).
- *Reactivity*: agents perceive their environment and respond in a timely fashion to changes that occur in it.
- *Pro-activeness*: Agents do not simply act in their environment, but they can also take initiatives. The application domain of applying agent technology is crucial as we always have to balance between risk and trust when working with software-based systems.

Usually each software agent is a different specialist, able to accomplish certain tasks, thus providing co-operative members in a society. In this work, the scenario of knowledge co-operation will illustrate how certain components (i.e. chain requirements) can be monitored from a multi-agent software system, by using intelligent specialised software agents, which will simulate the procedure of data analysis to extract useful information for the logistics network and send the appropriate messages to each level as described in the next section.

The general architecture of each individual intelligent software agent, as shown in Figure 1 includes the body, head and the communication abilities (grey box). The body contains all the centralised processes, tasks given to each agent to accomplish which can be different, depending on their role. The head includes the information provided either from the user or the other software agents and the grey box includes all the functions required in order for the agents to be able to communicate and as a result co-operate with other members of the agent society. This successful combination of several autonomous intelligent agents working together is called multi-agent systems.

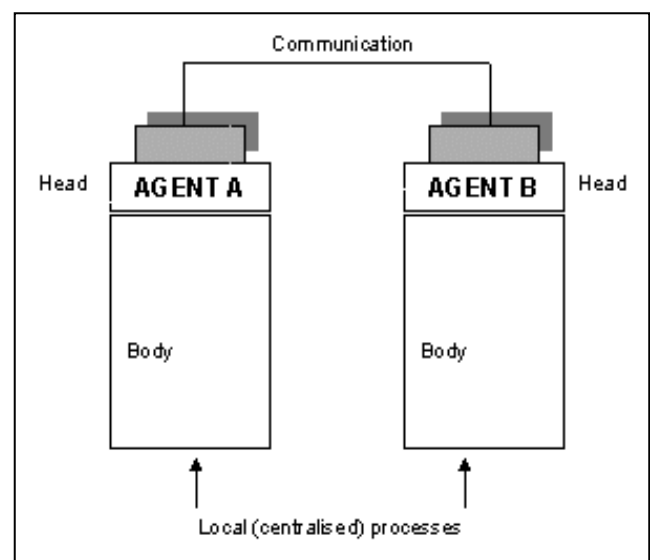


Figure 1: Intelligent Agents

### 3. Chain Optimisation via Intelligent Agents Technology

A large array of software applications for planning and optimizing performance of supply chain is currently on market. These applications include Materials Requirement Planning (MRP), Manufacturing Resources Planning (MRPII), Enterprise Resource Planning (ERP), and Advanced Planning and Scheduling (APS). Most of these applications are focused internally within an enterprise. Inter-organisational communication is usually effected by mail, phone, fax, email, or electronic data interchange (EDI). However, EDI systems are expensive for small and medium enterprises. As a result, information flow in supply chain is normally pipelined sequentially, paused to each chain echelon, while human intervention imposes costs, delays, and errors.

The advent of the Internet has led to the emergence of new business models. Companies can now collaborate closely with all partners in the supply network. Collaboration can take place in different levels: share forecasts, manage inventories, schedule labour, or optimize deliveries. Software for Business Process Optimization (BPO) and Collaborative Planning, Forecasting and Replenishment (CPFR), is correspondingly evolving to optimise end-to-end supply networks.

Agents technology has been usefully used in automated electronic third party mediation (or brokering) mechanisms in various commerce transactions and marketplaces [18]. Agent brokers can be a non-obstructive, external dimension of existing buyer-seller relations and may only serve as a go-between and gatherer of pricing information, other service provider. Neubert et al. propose an intelligent negotiation agent, capable to assist human decision-maker supply contract negotiations, thus resolving conflict through the harmonisation of individual interests [14]. Vulkan and Jennings found that autonomous, automated agents give promising results in auction negotiations of the supply of services within the context of a BT British Telecom project [21].

Nissen explored the application of agents technology in supply chain integration of a medium-sized US government facility and found that it may have better results than web-based supply chain technologies [15]. Kimbrough et al. simulated the Beer Game having artificial agents instead of human to manage an electronic supply chain [11]. They found that agents were able to track demand, eliminate the Bullwhip effect, discover the optimal policies (where they are known), find optimal policies under complex scenarios, and add adoptability of the supply chain to business environment fluctuations. Gerber et al. presented an agent-based information and trading network (ITN) for dynamic production and sales of timber and found that simulated trading mechanism as well as matrix auction mechanisms were especially suitable for supply web co-ordination and optimization tasks [8].

### 4. Re-engineering supply chain using intelligent agents' technology

The main concepts of this work appear to be similar with the main concepts of the multi-agent-based technology introduced by Ferber [5]. The key aspects of this, based on the previous discussions concerning the nature of the problem are:

- The identification of certain relationships within an electronic marketplace has been mapped to a 'communication' problem where different kinds of agents seek to exchange messages to satisfy and interpret data on an on-line basis.
- The agents are autonomous entities and they either work on their own or co-operate with others under certain conditions and based on certain relationships.

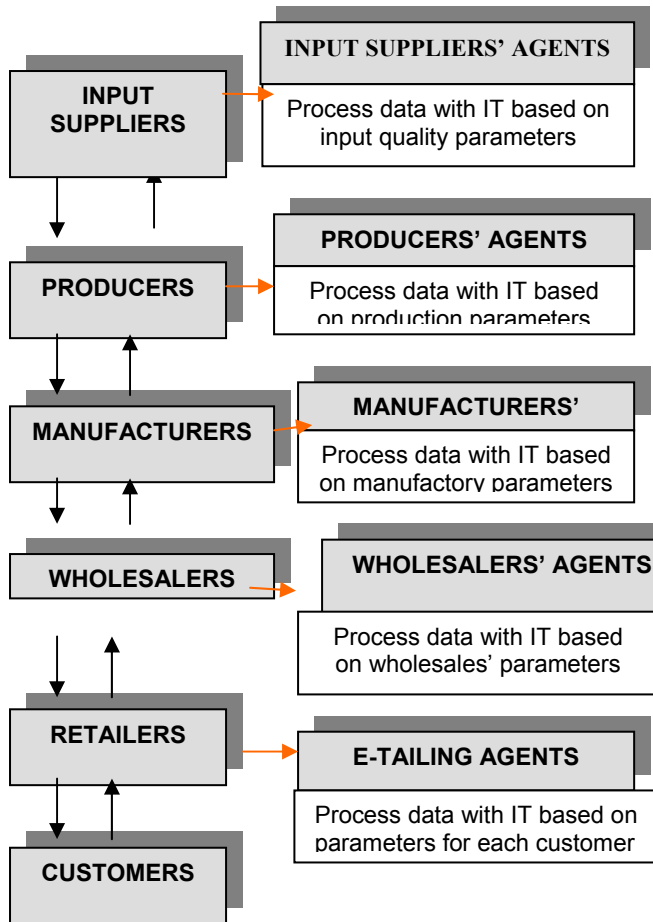
The philosophy of this work is based on a dynamic multi-agent software system, which employs communication skills, with decision-making functions for data interpretation in supply chain management. The information environment within any large organisation is extremely complex. Describing who holds what information, how it is used and from where, how it can be better interpreted to derive meaningful conclusions, are very complex tasks but their importance has been accepted from all the companies in the market. Systems that can help aid the process of data interpretation and recognition of the types of information within a retailer and its value in relation to the supply chain management are therefore extremely important. In order to explore the importance of the multi-agent system development, a theoretical framework is being proposed. Specialised software agents will be able to automatically process the data and give information about the different levels of the supply network, based on certain attributes (i.e. cost, quality, safety, trace-ability, competitive advantage etc.). These will be the results from identification of the main characteristics of a well-managed process:

- Defined ownership
- Defined boundaries of each level within the chain
- Defined flow of information between the different levels
- Established control points within the whole marketplace
- Established measurements

The proposed software system overcomes today's problems, as it supports the use of more than one computational intelligence technique through agents' technology. The key function is the application area of interpretation of the available data. Considering a software system responsible for data interpretation, there can be distinguished a number of interesting characteristics as shown in Figure 2:

- The process is distributed. There can be distinguished a number of autonomous processes (data gathering from retailers, data grouping etc.), which interact with each other to end up with a meaningful conclusion.

- The distributed problem domain denotes the development of a hierarchical layered software system, which results in the construction of a structured society of agents, with different groups, each one specialised and with different functionality.
- The software system as a whole has to be easily maintained, as new agents might be included, if new products or manufacturers have entered the market.
- Finally, the requirements of such an automatic system for data interpretation in marketing are high, as it deals within a dynamic environment, where any change is possible, and the system has to be accurate.



**Figure 2: E-marketplace towards a multi-agent system for supply chain management**

The novel idea of this framework is the construction of an agent society, in groups, based on the hierarchical reasoning during the interpretation procedure, which benefits from the agent technology in terms of decentralisation of execution, decentralisation of control and existence of co-operation. Every software component within a multi agent system has to carry out problem solving actions in order to achieve its goals. When acting on their own, their functionality determines the right actions to perform in certain situations. Within a multi-agent system though it has to consider the actions of the other software components as well, based on the principle of social rationality as given in [9]: “Within an agent-

based society, if a socially rational agent can perform an action so that agents’ joint benefit is greater than their joint loss then it may select that action”.

Based on that the expected utility of an action is given from the equation:

$$EU(a) = f(IU(a), SU(a))$$

where  $EU(a)$  is the expected utility of an action “a”, which is given from the combination (based on some function  $f$ , depending on the application) of the individual utility ( $IU$ ) and the social utility ( $SU$ ). It means that in order for an agent to perform an action it has to consider both its own and the society’s loss (or gain). Rationality refers to the successful performance of an action. The only assumption within this theory is that the intelligent agent requires complete information and sufficient time to carry out the necessary reasoning.

The whole procedure of communication between these different kinds of agents also offers at the end the positive result of improved interpretation, a flexible architecture and adaptability.

## 5. Communication

In order that agents achieve their goal, they have to communicate their knowledge, which can be accomplished through the Agent Communication Languages (ACL) in a standardised way, by using communication protocols including TCP/IP, SMTP and HTTP to exchange any type of knowledge needed.

The best known ACL is that of the DARPA knowledge sharing effort, which led to the successful development of the Knowledge Query Manipulation Language (KQML) [6] and the Knowledge Interchange Format (KIF) [7]. Much research is being performed by the Foundation for Intelligent Physical Agents (FIPA), an international body that aims to set general standards for agent interoperability. FIPA have defined an ACL (FIPA ACL), which includes basic communicative actions (such as *inform*, *request*, *propose* and *accept*) together with a number of interaction protocols including the contract-net protocol.

In distributed multi-agent systems the agents themselves may be transmitted across a computer network and executed remotely. Such agents are called *mobile agents*. In these architectures the agent software is transmitted to the host computer, the data are processed and the final result is communicated back.

### 5.1. KQML

KQML is both a message format and a message-handling protocol to support run-time knowledge sharing among agents for co-operative problem solving. It employs a layered architecture of communication, where at the bottom the functionality for message transport or communication occurs and at the top the content is specified by the application. Consequently, it provides the agent designers with a standard syntax for messages, and a number of performatives that define the force of a message, while letting them decide the content of the messages. Examples of performatives include *tell*, *inform*, *perform*, *reply* and each one is associated with a

set of parameters indicated by “:”. The inspiration for these message types comes largely from speech act theory, in order to cope with problems associated with large-scale knowledge bases, which are sharable and reusable.

The performatives support the development of higher-level models of inter-agent interaction such as contract nets and negotiation. KQML provides a basic architecture for knowledge sharing and the underlying communication is asynchronous, because it assumes the message transport is reliable and preserves the order of messages, but may not guarantee delivery always.

## 5.2. KIF

Apart from the communication language, agents need to have an understanding and parse the content of the messages they receive. This is facilitated by Knowledge Interchange Format (KIF), which provides a syntax for message content, which is essentially first order predicate calculus with declarative semantics. This empowers the agents to understand the meaning of expressions in the representation without the help of an interpreter for manipulating those expressions. KIF is logically comprehensive, as it includes mechanisms to support the expression of arbitrary sentences in first-order predicate calculus. It also provides methods for the representation of knowledge about the representation of knowledge (meta-knowledge) and plays the role of mediator for declarative knowledge bases and knowledge representation languages (i.e. PROLOG, LISP and XML). The language description includes both a specification for its syntax and one for its semantics. For example, in order for an agent to reason based on salaries of different employees it needs to have knowledge of the employees’ id, the department they are working for and the amount of their salary:

(salary ?id ?department ?salary)

and the representation of the agent’s interest in different salaries:

(interested agent (salary ?x ?y ?z))

## 5.3. Ontology

Based on the domain experts’ reasoning for solving complex problems, the requirement for a domain specific vocabulary has been identified, as traditional representation languages are domain independent. Ontologies have been developed in order to provide a domain specific vocabulary for inter-agent communication. In the context of knowledge sharing the term “ontology” is used as a description of the concepts and relationships that can exist for an agent or a group of agents in a defined set of formal vocabulary. This means that in order for the agents to communicate in an efficient way, they have to use a formal context of knowledge representation so that they infer the same meaning for the same concepts referenced. The set of objects and the relationships between them are represented in a logical formalism of a vocabulary. There are certain definitions associated with the names of the different entities within the problem domain (types of entities, their attributes and

their properties, the entities’ relations and functions and any of their possible constraints) in a human readable text describing what these names mean and certain axioms that constrain their interpretation. In a multi-agent system the agents share the same vocabulary, but this doesn’t mean that they share a knowledge base. Each agent might have different knowledge to that of the others, but a shared vocabulary is essential in order to achieve their communication in a coherent and consistent manner.

## 6. Multi-agents architecture for chain optimisation

This section introduces the novel idea of a hierarchical decentralised multi-agent architecture developed for data interpretation and monitoring supply chain management. It employs different groups of intelligent agents to cope with the variety of application functions by using distributed problem solving. The design and functionality of the diversity of agents, along with the key issues behind the multi-agent system as a whole, are described.

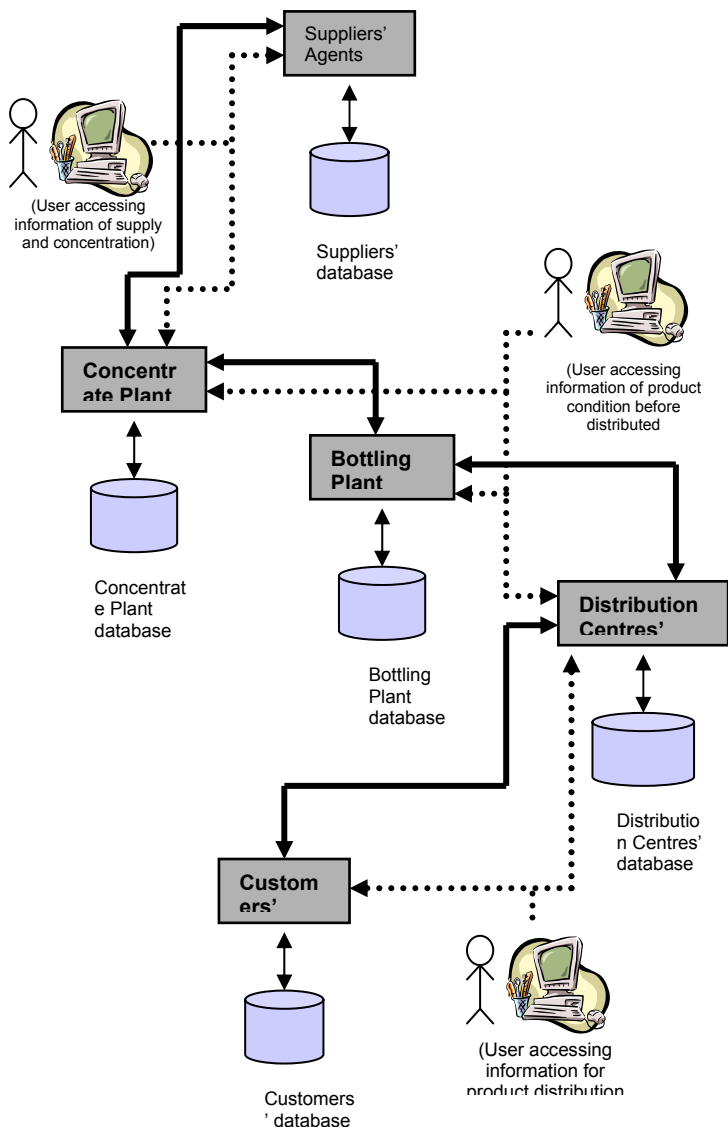
The establishment of the application requirements has firstly to be considered before the software development. During the analysis of the supply chain management process, there are a number of functions specified, which indicate the need for heterogeneous groups of autonomous software entities as described in the previous section. In order to avoid any complexity issues concerning the development of the multi-agent system, the problem has been viewed from a high level of abstraction at the first stage, which as a consequence will lead to the individual agents’ specification and functionality.

The role modelling procedure is similar to the one of the GAIA methodology [22], according to which abstract roles are identified. In each one there might be other sub-roles defined depending on the specified application. As a consequence, during the design process, the roles and interactions between all the agents are identified and will be used to implement the multi agent system for supply chain management.

Within the supply chain management, the agents can be used to monitor the business units or facilities that purchase the raw material, and how these can be converted into intermediate goods and final products, which then are being delivered to the customers. The supply chain then can be efficiently co-ordinated, to ensure that the products pass through the chain in the shortest time and at the lowest cost, as agents can be used for sharing information on the network of different companies and negotiate about product prices [20].

For reasons of brevity we omit the details of the described case study and focus on the analysis and design of the software components instead. The particular application is providing customers with certain quantities of beverages. This activity involves the understanding of the system’s organisation, while viewing it as a collection of roles that stand in certain relationships to one another

and have certain interaction patterns. Figure 3 denotes the architecture of a multi-agent system for the supply chain for beverages, where the interaction between certain type of agents is predefined and the users depending on their profile have access to certain information at any time.



**Figure 3: Agent-based supply network**

Table 1 illustrates the key roles for a supply chain management multi-agent system and how these are used within the specific supply chain for beverages. The different protocol activities, permissions and responsibilities associated with each role are given, which will assist the different software components to achieve the mission of the logistics, which is to get the right goods or services to the right place and the right desired time and the right condition, while making the greatest contribution to the firm. At the same time the intelligent agents' functionality will provide one more advantage, which is to deliver the right information to the right user the right time.

**Table 1: Schemata for agent roles**

<b>Role Schema: InputSupplier</b>	
Description: Receives quote request from the producers' agents and ensures that the appropriate input quote is sent.	
Protocol and Activities: WaitForRequest, CheckQuote, InformSupplier	
Permissions:	<b>supplierInput</b>
<b>read incomingRequest</b>	
Responsibilities: Trust, Negotiation with supplier	
<b>Role Schema: Producer</b>	
Description: Receives quote request from the manufacturers' agents (Concentration Plants in our case study) and ensures that the appropriate quote is sent to the input suppliers.	
Protocol and Activities: WaitForRequest, CheckQuote, InformProducer	
Permissions:	<b>manufacturersInput</b>
<b>read incomingRequest</b>	
Responsibilities: Trust, Negotiation with producers	
<b>Role Schema: Manufacturers</b>	
Description: Receives quote request from the wholesalers and ensures that the appropriate information is sent to the producers.	
Protocol and Activities: WaitForRequest, CheckQuote, InformManufacturers	
Permissions:	<b>producersInput</b>
<b>read incomingRequest</b>	
Responsibilities: Trust, Negotiation with manufacturers	
<b>Role Schema: E-tailing</b>	
Description: Receives quote request from the customers electronically and ensures that the appropriate quote is sent to the manufacturers.	
Protocol and Activities: WaitForRequest, CheckQuote, InformDistributors, InformCustomers	
Permissions:	<b>distributosInput</b>
<b>read customersInput incomingRequest</b>	
Responsibilities: Trust, Negotiation with distributors	

An example of an agents' dialogue, based on the different roles and the given ontologies is illustrated in Table 2, where a customer posts its order and two different distributors reply. At the end the customer's agent will select the distributor with the best price and time delivery. This can be specified by evaluation functions, predefined within the agents' knowledge. Based on the latter mentioned roles, the software system will be able to monitor on-line the supply chain management of beverages, which can be on-line evaluated based on the Inventory Model.

## 7. Discussion

There are great general benefits and savings to be gained by the use of intelligent agents for supply chain management. Initially, optimisation agents can be the building block of a correct designed simulation for an accurate representation of a supply system. The monitored supply chain can be driven temporarily beyond its maximum capacity through the knowledge of the multi agent system based on the behavior of the different layers of the supply network. Additionally the efficiency of the supply chain may be increased through the elimination of unexpected mistakes. Potential supply errors will be identified while they are still in the incipient stages.

**Table 2: Example of KQML dialogue for MAS**

```

Dialogue:
(orderFromCustomer
  : sender CustomerA
  : language KQML: ontology E-tailingForBeverages
  : content
    (stream-about
      : language KIF : ontology beer
      : content c1
    ))
(replyToOrder
  :sender DistributorX : receiver CustomerA
  : reply-with d1
  : content
    (stream-about
      : language KIF : ontology beerDistribution
    ))
(replyToOrder
  :sender DistributorY : receiver CustomerA
  : reply-with d2
  : content
    (stream-about
      : language KIF : ontology beerDistribution
    ))
(tell
  : sender DistributorX :receiver CustomerA
  : in-reply-to c1 : content (= (beer 500) (deliver
15.00)))
(tell
  : sender DistributorY :receiver CustomerA
  : in-reply-to c1 : content (= (beer 400) (deliver
16.00)))

```

While not directly preventing the occurrence of the system error, the unexpected element of a mistake may be eliminated and the supply can succeed with minimum losses at each layer of the chain. Some of the main contributions of the system proposed in this paper include:

- **Flexibility:** Agents technology can be non-obstructive of existing buyer-seller relationships. Trust, mostly the lack of it, has been repeatedly found to moderate of buyer-seller relationships [2] [12] [17] [16]. Typically, the application of Information Technologies alters the trade relations. Empirical studies suggest that

powerful partners take advantage of IT technologies to gain more power or impose their strategy to smaller partners. However, IT applications don't necessarily have to be obstructive in order to be effective. For example, Bakos and Dellarocas describe online reputation mechanisms as an emerging alternative to more established mechanisms for promoting trust and cooperative behaviour, such as legally enforceable contracts [1]. Das and Malek, who defined supply chain flexibility as the robustness of the buyer-supplier relationship under changing supply conditions, found that order quantities and supply lead-times are the two most common factors associated to flexibility [3]. Intelligent agents can manage orders effectively and reduce lead times thus the flexibility of the chain increases. These advantages are attributed to the following abilities of the multi-agent system:

- The analysis and design of the layered architecture has been defined and the different roles of groups of intelligent agents have been specified to map the procedure of supply chain management.
- The advanced web-based graphical *user interface called the Supply Assistant Agent (SAA)* will assist the users of the software depending on their user profiles to view certain information of the system and to control and if necessary interfere by sending the appropriate message to the intelligent agents of certain layers.
- A number of different intelligent agents will be able to derive information relating to the state of a product, within the supply chain from measurement data and from communication with the user and between different layers of the supply chain.
- The multi-agent system will be easily extensible due to its object- oriented design and development, which also means that it can be reused for different kind of supply chains.
- **Information visibility:** visibility of appropriate information into a distribution network is necessary in order to optimize scheduling and planning costs. Information visibility means having the right data at the right time. As a consequence, the success of any technological improvement depends on delivering information visibility into the system. Agents' technology has this advantage of having access to the different layers of information, even in cases where information has been processed from different techniques.
- **Efficiency:** Forestalling the Bullwhip effect fire-fights the explosion of many supply problems such as: excessive inventory, severe delays, poor product forecasts, unbalanced capacities, poor customer service, uncertain production plans, high backlog costs, and lost sales.

Despite the obvious advantages, there are a number of issues to be considered associated with the analysis and design of such a software system at the operational,



tactical and strategic level. We found that (a) there are data-related concerns at the operational level. Data & information sources need identification and filtering prior to processing. Problems we expect to find here are incomplete or missing data, data handling difficulties, or unreliable and inaccurate data sources. Specified security mechanisms have to be predefined as well, so that different end users have access to specific information. (b) Process-related concerns at the tactical level. In particular, process complexity, which is the speed of negotiation among the agents and the distribution of functionality to the different layer of software components, has to be specified. (c) Partner-related concerns at the strategic level. Partners should be willing to share information at tactical and operational level. Although a minimum level of trust should be expected, using optimisation agents, it is not prerequisite for business partners to share or expose strategic information (i.e. demand forecasts).

Additionally, a number of issues should be taken into account, during the software development that are of high importance for future research within the area of intelligent agents' application in supply management:

- *Trust*: in a web-based marketplace, it might be difficult for consumers and producers to know who is reliable and secure.
- *Privacy and Security*: there must be predefined access to certain type of users to certain information and there is a high concern from the consumers and producers of the security of their personal information when using e-commerce systems
- *Billing/Revenue*: there are no billing mechanisms so far developed for similar applications and it must be implemented over the basic web structure
- *Reliability*: data and connections must be reliable and with predictable performance.

It should be emphasised that agent-based systems are not a panacea for solving every type of problem. They suffer from all the problems associated with the process of gathering human expertise and converting it into a reusable knowledge base. However, the MAS development has proved to be efficient, especially in cases where there is an environment that changes over time, different distributed processes need to take place, and their results need to be correlated, like this one of supply chain management.

Future research should aim to quantify the advantages of agent technology as discussed above. We suggest the simulation of the optimisation agents effect on beverages supply network, measuring and comparing specific indicators such as inventory level, distribution costs, total logistics cost savings, life cycle time, etc. Optimisation agents can be used in supply networks with time, cost, and efficiency as critical elements. In this respect, optimisation agents can be successfully applied to sectors such as electronics and machinery, including agricultural machinery.

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