Resilience Modeling of Value Chains

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***Abstract* - Resilience Modelling of Value Chains involves changing behaviours of the occupied entities dynamically, hence we need an adaptive, flexible and responsive solution to achieve this scenario. Multi Agent Systems could provide a common space for enabling the interaction among Value chain entities. This paper describes the development of an agent-based software system for assisting in decision making regarding value chain management and to achieve resilience modelling of value chains in the milk powder industry in Sri Lanka. Such a system can be applied to different types of industries with some domain specific modifications. The core architecture is built around the concept of Multi Agent Systems since Agent Technology has been identified most suitable for modelling complex scenarios.**

1 INTRODUCTION

Being an essentially required food by every person, irrespective of age, gender or social status - milk, as a liquid food demands a high value. Amidst such high consumption, price of milk powder is getting higher and higher day by day, globally. We being Sri Lankans face this challenge as it is milk powder is the commonest among us. For its convenience and greater availability milk powder has become common milk source in every household [27]. The dependence of imported milk powder should be reduced and the use of local milk to produce milk powder should be promoted other than promoting the use of liquid milk. Hence the resilience modelling of the local milk powder value chain is essential in order to promote the use of local milk powder in Sri Lanka.

Effective management of value chain dynamics in today's IT driven global economy has become a key to success in almost every organization. The management of value chains has become a complex process due to the uncertainty of customer demand, market variations, increasing complexity of business processes, and numerous competitors' as well unforeseen events during fulfilment.

Multi Agent Systems has been identified as the best approach to model such complex scenarios because of the important features of Multi Agent Systems such as autonomy, adaptation to environmental conditions, intelligent and learning ability. The motivation of this project is to use Multi Agent Systems to model Value Chain Dynamics in today's IT driven global economy in order to achieve value chain resilience.

Each business process of a value chain should produce an output with a value to the customers. Value is considered as a measure of customer satisfaction about the purchased goods and services [13].

In general, resilience is the ability of a system to return to its original state after being disturbed. [15] Apart from the issue on dynamic business processes of interconnected and distributed business entities , the study on information flow within the supply chain entities is equally important in order to implement an effective network of a value chain [9].

Other than the above two issues value chain resilience is highly affected by the correctness of the decisions made by the managers regarding production planning, inventory management, vehicle routing etc. There are many constraints need to be satisfied prior to make those decisions such as production, shipping and inventory capacities, precedence order of activities, legal obligations, etc. Further these decisions are interdependent as well the companies in a supply chain are interconnected in today's global market which makes the task of achieving resilient and agile value chain is much more complex [20].

The unforeseen or incorrectly predicted customer requirements could result a phenomenon called bullwhip effect. This event occurs when companies significantly cut or add inventories. Economists call it a bullwhip because even small increases in demand can cause a big snap in the need for parts and materials further down the supply chain which will lead to consumer dissatisfaction and wastage of inventories [26].

Thus the complicatedness of value chain management related to uncertain and dynamic behaviour of the modern global market should have to be handled effectively in order to achieve value chain resilience. The existing traditional systems have been failed to provide an integrated system to achieve the resilience modelling of value chains because of the complexity in the real world business processes.

Section 2 describes some existing value chain management systems in the literature. Next section discusses about the agent technology used to realize the system. Section 4 provides an overview of the proposed solution and section 5 depicts the design of the system. Section 6 is about the implementation and section 7 reports the evaluation of the system and the next section discusses the overall achievements of the project as well about future work.

2 STATE-OF-THE-ART

MAS have become a promising technology for modelling complex real world scenarios thus it has been identified as the best technology for value chain modelling. A vast number of growing multi agent based applications in this field could be found in the literature.

The current approaches for agent based value chain modeling could be categorized in to two main groups as value chain management projects and value chain design projects. Moreover, the manner of solving problems also differs depending on projects. E.g. the number and the role of agents vary considerably, depending on the particular point under study

2.1 The Beer Game

The Beer Game is an agent based simulation model for designing value chains. This has been developed as a game which involves a simple production and distribution system for a single brand of beer. Beer Game created by a group of professors at MIT Sloan School of Management in early 1960s to demonstrate a number of key principles of supply chain management. [22]

The purpose of the game is to meet customer demand for cases of beer through a multi-stage supply chain with minimal expenditure on back orders and inventory. How the phenomenon of bullwhip effect is originated in a value has been clearly presented in this game. The game is developed using Agent Based Simulation techniques.

2.2 TAC SCM

The Trading Agent Competition Supply Chain Management scenario (TAC SCM) is a competition which is aimed to encourage the developers to implement and to test agent based solutions for supply chain management. Autonomous software agents must perform the operations in value chain management such as planning for the procurement of materials, assembly of finished products from these materials, and distribution of products to customers. As well the agents should be capable of making predictions about the future of the economy, such as the prices that will be offered by component suppliers and the level of customer demand, and then planning its future actions in order to maximize profits [4]. In each year a winner is selected with the best agent based supply chain management software.

2.3 MASCOT

Multi Agent Supply Chain Coordination Tool (MASCOT) is a reconfigurable, multilevel, agent-based architecture proposed by Norman M. Sadeh, et al in order to coordinate supply chain planning and scheduling [19].The tool has been designed to support effective production and to enable the quick and accurate evaluation of new product/subcomponent designs and strategic business decisions throughout a supply chain. There is a MASCOT agent at each stage of the value chain providing the functionalities such as coordination and integration among planning and scheduling modules, decision support, reconfiguration etc.

2.4 DASCh

DASCh project was developed in order to explore the dynamics of a supply network with the use of Agent Based Modeling [11].There are three types of agents involved in the system as company agents, PPIC agents and shipping agents. Company agents represent the different firms in a supply network and they use inputs from their suppliers and transform them into outputs that they send to their customers. PPIC agents model the Production Planning and Inventory Control algorithms used by company agents to determine what inputs to order from their suppliers, based on the orders they have received from their customers. Shipping agents model the delay and uncertainty involved in the movement of both material and information between trading partners.

2.5 Agent-based Mix-game Model

Chengling Gou at Beijing University of Aeronautics and Astronautics has developed an agent based mix-game model in order to simulate financial markets [2]. In mix-game, there are two groups of agents; group1 plays the majority game, and the group2 plays the minority game. N is the total number of the agents and N1 is number of agents of group1. The system resource is R=0.5*N. All agents compete in the system for the limited resource R. T1 and T2 are the time horizon lengths of the two groups of agents, and m1 and m2 denote the history memory lengths of the two groups of agents, respectively.

2.6 Integrated Multi-agent-based Supply Chain Management

Daniel Frey and his colleagues have developed a MAS architecture that integrates various intelligent agent systems for supply chain planning and execution tasks [3]. The system was proposed as MAS to integrate different existing MAS in order to provide the required functionalities.

2.7 Multi Agent Architecture for a Dynamic Supply Chain Management

José Alberto et al have proposed MAS for addressing the value chain management in a dynamic, distributed environment. The typical tasks of the agents involved in the system are bid planning, production scheduling and supplier negotiation [12]. There are agents to represent each stage of the supply chain and a knowledge base to store the knowledge. Agent based modeling approach has been taken in order to model the supply chain.

2.8 EMCAS

The Center for Energy, Environmental, and Economic Systems Analysis (CEEESA) of USA has been developing EMCAS, the Electricity Market Complex Adaptive System model. Here the different participants in the electricity market are represented as agents. It is a large scale agent based simulation model of the electric power market. The agents have their own set of objectives, decision-making rules, and behavioural patterns. Further, agents can draw on an array of historical information (e.g., past power prices) and projected data (e.g., next-day load) to support their unique decision process. EMCAS is an example of an agent-based model that has been successfully applied to a real-world policy issue [7].

However the proposed system which integrates the supremacy of Agent based modeling with Optimization which is distinguished from those existing systems.

3 AGENT TECHNOLOGY FOR RESILIENCE MODELING OF VALUE CHAINS

3.1 Motivation for using Agent Technology

Value chain management in today's dynamic, distributed and interconnected business environment is a complex task. In order to model this complex behavior the use of agent would be the ultimate solution.

Agents are sophisticated computer programs that act autonomously on behalf of their users, across open and distributed environments, to solve a growing number of complex problems [29].

According to Wooldridge and Denning [17] an "agent" indicates a hardware or software-based computer system that has the characteristics of Autonomy, Social ability, Reactivity and Pro-activeness.

Capacity to operate without the direct intervention of humans or others and to have some kind of control over its actions and internal state is described by the feature of Autonomy of agents. The implementation of consumers and value chain entities as agents will allow them to carry out their tasks by themselves without external intervention thus allowing autonomy in decision making procedure.

Social ability of the agents has been used to model the consumer market effectively. The consumer market is modeled using 100,000 agents. And the consumer agents are affected by the advertisement effect and by contacting each other. This would be the normal scenario in any consumer market model where consumers tend to buy products because of the effect of advertisement or the effect of word of mouth. Thus agent technology has provided the best opportunity to model the consumer market with their social ability. Moreover companies in the value chain are interacting with one another, thus the social ability will be essential.

Reactivity of agents will help the companies to properly perceive their environment consist of the market and other companies and enable them to respond in a timely fashion to the changes occur in it. Thus each company would successfully adapt to the market and competition evolutions. The ability of companies not only to react to the environment but also to initiate new activities such as launching new products on the market would be achieved by the proactive behavior of agents.

Apart from the above mentioned features of agents the following agent features have also played an important role when achieving resilience modeling of value chains. Agents are capable of adapting to the environment in contrast to the pre programmed behavior of traditional programs. Thus when the environment of the market is changing the consumer agents as well the value chain entities can adjust their behavior to suit with the new situations. This would be used to achieve a resilient value chain.

3.2 Motivation for using Multi Agent Systems Technology

Since there are multiple business entities involved in a value chain which are interconnected and geographically distributed, different agents that can work together are required by the proposed system. Thus the Multi Agent System (MAS) Technology has been used to cater the previously mentioned requirement. A multi-agent system is a loosely coupled network of software agents that interact to solve problems that are beyond the individual capacities or knowledge of each problem solver [29].

Supply chains are made up of heterogeneous production subsystems gathered in vast dynamic and virtual combinations. Autonomy of each member in a value chain would be increased with the use of an intelligent distributed system like MAS. Each partner in the value chain pursues individual goals while satisfying both local and external constraints. Therefore, one or several agents can be used to represent each partner in the supply chain.

Moreover, the agent paradigm is a natural metaphor for network organizations, since companies prefer maximizing their own profit than the profit of the supply chain. In fact, the distributed manufacturing units have the same characteristics as agents.

Moreover MAS have been used to implement production systems and business processes across the value chain in a decentralized, emergent and a concurrent manner [22].

As well the unique features of multi agent system such as communication, coordination and negotiation helps the resilience modelling in value chains possible.

3.2 Ontology

Ontology in MAS is the place where the knowledge required to carry the agent behavior is stored. This is modeled using XML (Extensible Markup Language) and java due to the large number of information needed to be kept in the ontology. Additionally dedicated ontology development tools could also be found.

4 RESILIENCE MODELING OF VALUE CHAINS

In this approach value chain modeling is addressed from perspectives of the plan execution dynamics under uncertainty thus enabling adaptive modeling. The intended tasks of each agent could be listed as follow.

1. The customer places an order with the retailer.
2. The retailer fills the order immediately from its respective inventory if it has enough inventories in stock (if the retailer runs out of stock, the customer's order is placed on backorder and filled when stock is replenished).
3. The retailer receives a shipment from the upstream wholesalers in response to previous orders. The retailer then decides how much to order from the wholesaler based on the knowledge obtained by the environment. The ordering decision is based in part on how much the retailer expects customer demand will be in the future. The retailer then orders items from the wholesaler to cover expected demand.
4. Similarly, each wholesaler receives a shipment from the factory, forecasts future demand by the downstream retailer, and places an order with the factory. This process will be continued up in the value chain to the factory.

Moreover the value chain agents are capable of performing the below functions.

1. When the consumer demand is at a lower level the retailer agent perceives that and prevent from selling products in order to create an increase in the consumer demand.
2. When retailer agent does not sell products the consumer agents are waiting. The wholesaler agent recognizes it and start selling products directly to the consumer agents.
3. The retailer agent distinguishes the above scenario and reduces the price of the product.
4. The retailer agent increases the price of the products when the consumer demand is increasing.
5. The wholesaler agent perceives that and start selling directly to the consumer agents in order to prevent the loss.
6. Hence the retailer agent again reduces the price of the products.

The above functionalities of each agent are achieved through message passing among the relevant agents and the additional knowledge required to execute the intended functionalities such as market information, rules would be kept in ontology where every agent will have the access to the ontology. The communication among request and resource agents would be facilitated via the message space.

5 DESIGN

The top level architecture of the system is designed according to the concept of message passing among request and resource agents of the system as depicted in the figure 5.1.

5.1 Consumer Agent Module

Consumer module is used to identify customer buying patterns effectively and to make the value chain resilient by enabling the adaptation based on consumer requirements. The market is modelled with 100,000 consumer agents. The milk powder packet is being sold to the consumers who are sensitive to the advertising as well as word of mouth. Initially there are no users of the product and the advertising generates the demand of a product and the consumers who are potential users for the product will become users of the product. When a user contacts with another potential user he will also become a user with the affect of word of mouth. The communication among consumer agents is achieved through message passing among each agent.

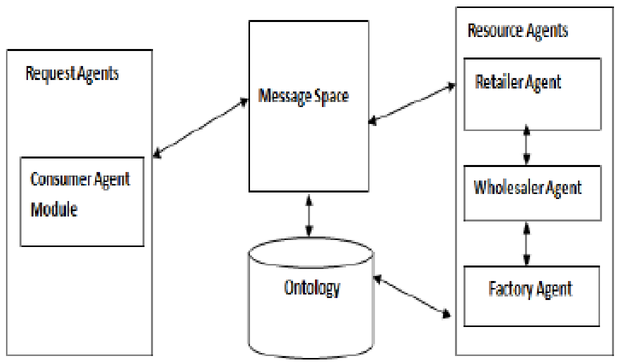

Figure 5.1: Top level Architecture of the system

5.2 Value Chain Agents

The consumers, retailers, distributors, assemblers and factories have been modeled as value chain agent modules.
Retailer Agent: When an order is placed by a customer it would be fulfilled by the retailer agent immediately from its respective inventory if it has enough inventories in stock. Otherwise the customer's order is placed on

backorder and filled when stock is replenished. Retailer agent would make orders to the wholesaler agent. The decision about the amount to order is supported by knowledge obtained from the environment mostly the predicted consumer demand.
Retailer Agent is capable of perceiving the consumer demand and act accordingly in a way that maximizes the profits.
Wholesaler Agent: The wholesaler agent would place orders with the upstream Factory by forecasting the future demand from the downstream retailers. The forecasting would be facilitated by the knowledge about existing marketing conditions. The knowledge required to do forecasting and to execute the business processes in each workflow is stored in the ontology.
Wholesaler agent is capable of selling products directly to the consumer agents in situations where the retailer agents prevent from selling in order to increase the consumer demand or retailer agent increasing the price.
Factory Agent: After any orders are shipped to the wholesaler, the factory reviews its current inventory level and decides how many items to manufacture. When a batch of items has been completed by the factory, the items are added to the factory's inventory. And it would be supplied to the wholesalers according to the demand.

5.3 Ontology

Ontology is used to store the knowledge required for the execution of agents and to enable interactions among each others. The information such as product description catalogues, market conditions, consumer data would be stored in the ontology as xml files and also as java files.

5.4 Message Space

Message space is modeled as an agent that can be accessed by all agents. Each agent writes their messages to the message space hence the other agents are able to respond to those messages.

6 IMPLEMENTING THE RESILIENCE MODELING OF VALUE CHAINS

The agent implementation has been done according to the FIPA standards and the communication of the agents is done using the ACL (Agent Communication Language). J2EE is used to implement the agent behavior according to the FIPA standards. AnyLogic IDE has been used to model the agent based value chain. Figure 6.1 depicts the interface of the implementation of the system for the resilience modeling of value chains.

6.1 Implementation of Consumer Agents

Each consumer is modeled as an agent and in the market there are 100,000 consumers. The communication among each consumer is done using message passing in ACL through the message agent. The advertising effect and the contacting rate of consumers determine the adoption rate of consumers to the product in the market. Initially all the consumers are potential users of the product and when the company starts the advertising the potential users will gradually become users. And the users will contact with the other potential users and once they contacted each other the other potential users will also become users of the product. The demand variation of the consumer agents with the time is modeled dynamically in the system.

6.2 Implementation of Value Chain Agents

The value chain agents include retailer agent, wholesaler agent and the factory agent. Implementation details of these agents are discussed below.

6.2.1 Implementation of Retailer Agent

The retailer agent communicates with the consumer agents and supplies the product according to the consumer demand. If it has not enough inventory in the stock the order is placed in the backlog and be fulfilled once the stock arrives from the wholesaler. The retailer checks the inventory level at the beginning of each day and decides how much to order from the wholesaler. When a shipment is arrived from the retailer it is used immediately to satisfy the backlogged customers. Retailer agent decides how much to order from the wholesaler agent based on the knowledge obtained by the environment. The communication among consumers, retailers and wholesalers is achieved through the message agent using ACL.

6.2.2 Implementation of the Wholesaler Agent

The wholesaler agent checks to see if there are any orders from the retailer agent and fulfill them immediately. The wholesaler receives shipment from the factory agent and they are added to the wholesaler's inventory. The wholesaler agent decides how much to order from the factory agent based on the knowledge obtained by the environment. The communication among the involved agents is done through the message agent using ACL.

6.2.3 Implementation of the Factory Agent

Factory Agent will fulfill the orders from the wholesaler immediately according to their priority level. After fulfilling the orders the Factory Agent checks its inventory level and decides how much to manufacture based on the knowledge obtained by the environment and the results of the optimization engine. The communication among factory agent and the wholesaler agent is facilitated through the message agent using ACL.

7 EVALUATION

The evaluation has been carried out to prove that the system is capable of functioning properly and effectively in a dynamic, interconnected and uncertain business environment. The results show that agents in the value chain are capable of achieving resilience by adapting to the changing market conditions, consumer demand etc.
The experimentations conducted to date has been done in order to illustrate the potential ability of the system to be adaptive for the uncertainties in consumer demand, value chain entity behavior as well uncertainties in the market environment. The considered scenarios are listed in the table 7.1.

Name	Description
1.Cost dominated transactions	This experiment runs using a predominantly "cost" sales environment
2. Demand boost	A sudden demand boost is modeled and how the system is being adapted to that is experimented.
3. Promotion volume is reduced	The promotion actions have been minimized and the value chain is experimented.
4. Demand Slump	A sudden demand slump is modeled and how the system is being adapted to that is experimented.

Table 7.1: Experimental Design of the model

The results show that the objective of resistance behavior with the ability to adapt to the new scenarios has been met by the proposed system.

8 CONCLUSION

Resilience modeling of value chain has been tried to achieve for a long period of time. There are number of systems such as ERP systems, workflow management systems etc. Almost all these solutions have been able to gain some level of resilience but in today's complex marketing environment all of them have found it impossible to achieve value chain resilience.
The paper discusses about a system to achieve resilience modeling of value chain with the use of agents for the milk powder industry in Sri Lanka. It has been proved that the agents are the best approach to model complex systems with uncertainty thus the rationality, autonomy and intelligence of agent has been used to achieve adaptive value chain management.
The proposed methodology contributes to advancing theoretical foundations of value chain modeling, supports managerial insight into supply chains at the tactical and operational levels, and serves to enhance decision-making in the planning of production and logistics networks. In future research, we will focus on further investigation into structure interrelations and their dynamics. As well the psychological condition of each consumer agent can be modeled when modeling consumer buying patterns.

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