

Modeling Supply Chains for New Ventures in Developing Countries

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Abstract

The purpose of this research is to successfully implement GlobalResolve's social entrepreneurship initiative in the Ghanaian village of Domeabra. This paper discusses some initial groundwork done by GlobalResolve toward setting up a gelled ethanol fuel business. The paper describes initial attempts to understand the various facets of conducting business in an informal economy, with a focus on designing and implementing sustainable supply chain solutions. Specifically, the paper describes the process of defining a supply chain in the context of a village in West Africa and addresses the challenges of modeling such a system. The work presented represents three separate, but related, strains of research. The first describes the use of agent-based simulation techniques to design and simulate various complex events in the supply chain. The second deals with the issue of price-quantity bargaining or negotiation and its impact on the supply and demand dynamic. The third introduces the idea of mobile phone use as an inexpensive and easily deployable method for transmitting critical information across various stakeholders in the supply chain. It should be noted this paper is exploratory in nature and is primarily aimed at documenting the initial groundwork done for a much larger supply chain modeling project.

Introduction

GlobalResolve is a social entrepreneurship program at Arizona State University (ASU) whose goal is to help solve problems of energy, health, and water in villages in developing countries by exploiting technological solutions to create sustainable business ventures run by and for the local economy. One of GlobalResolve's first projects aims to reduce indoor air pollution from cooking on open fires by helping a village manufacture gelled ethanol, a safe, non-polluting fuel. A gelled ethanol production facility was designed and fabricated at ASU. The facility was then delivered and installed in the village of Domeabra, Ghana in fall 2008, where it is beginning to produce gel fuel.

The GlobalResolve model of venture building involves identifying a problem, finding a satisfactory technology solution that can be created in the village environment, investigating the market for the product, and setting up a successful supply chain to produce and market the product. For the gel fuel project, Steps 1 and 2 have been completed, and Step 3 will be completed through a partnership with KITE, a non-profit development organization located in Ghana. As a result, the final step in the process of establishing a sustainable business in Domeabra, and the focus of this paper, is to begin developing a business plan that is successful for all members of the supply chain for selling the fuel and a companion stove in nearby urban areas.

Modeling techniques such as linear/integer programming and discrete event simulation have been well studied as tools to analyze critical factors (e.g., facility locations, production strategies) of supply chains in developed economies. Meixell et al. (2005), for example, discuss various techniques used to model supply chains using assumptions that are not viewed as an implementation challenge in developed countries. As a result, a number of standard approaches are widely available to assist with building and optimizing supply chains, provided the business operates within a set of assumptions, which often include: a well-developed transportation infrastructure exists, on-time delivery is a key performance metric, and products can be sold to internal and external customers at a price determined by the seller (Meixell et al. 2005).

Many of these assumptions do not apply to Domeabra or to villages in similar economies. In fact, Voordijk (1999) notes that the modeling and implementation of supply chains in developing African countries is not possible because basic conditions such as distribution infrastructure, communication channels, and production technologies are not present. As a result, modeling and implementing a supply chain in Domeabra will require significant modifications to standard approaches. This paper describes the process of defining a supply chain in the context of a village in West Africa and addresses the challenges of modeling such a system. Initial ideas are given for incorporating unique aspects of supply chains in emerging economies into standard models. Specifically, we discuss using Agent-based Modeling and Simulation to model the supply chain, the importance of modeling retail bargaining behavior, and the role of mobile phones in information transfer in supply chains for emerging economies.

Agent-based Modeling and Simulation (ABMS)

Supply chain design involves determination of i) the number and location of supply chain facilities, including plants, distribution centers, warehouses, and depots; ii) the transportation links and modes between facilities; and iii) the policies to operate a supply chain, such as inventory control policy, carrier loading policy, etc. (Ding et al. 2007) Simulation is an attractive supply chain modeling tool, as it allows for a wide variety of scenarios to be evaluated and/or compared in a relatively short amount of time without having to actually experiment on the real system. Simulation models can capture almost any degree of detail contained within the real system, provided supporting data exists, and allow for the portrayal of the dynamic nature of real systems. However, traditional Discrete Event Simulation (DES) models assume that the time at which changes to states of the system occur can be accurately described by an underlying equation or probability distribution. In the case of a supply chain in a developing economy, this modeling paradigm could be very difficult to implement.

An alternative simulation modeling approach is Agent-based Modeling and Simulation (ABMS), which is a relatively new approach for modeling systems comprised of autonomous, interacting agents. Rather than relying on underlying equations to model changes in the state of the system, ABMS represents elements of

the system (e.g., transportation mechanisms, retailers) directly as agents, each with their own set of rules and heuristics for how their behavior changes with time, rather than relying on a set of equations to model state changes for the entire system. Typical applications of ABMS include modeling the behavior of the stock market, supply chains, and consumer behavior, as well as predicting the spread of epidemics and the threat of bio-warfare or understanding the fall of ancient civilizations (Macal and North 2005).

Several studies also specifically study the application of ABMS to supply chain modeling. Santa-Eulalia et al. (2007), for example, propose a conceptual model for using ABMS for distributed supply chain planning, and Labarthe et al. (2005) used multi-agent based modeling to simulate customer-centric supply chains. Similarly, Barbuceanu et al. (1997) proposed the use of agents and coordination technology to model, design, and simulate global, distributed supply chains, and Swaminathan et al. (1998) modeled supply chain dynamics using multi-agent approaches. None of these studies, however, have examined the application of ABMS to supply chain modeling in emerging economies. As a result, the ABMS approach will need to be adapted to accommodate the cultural behaviors of the population in Domeabra. A brief discussion of the steps that would be involved in developing an agent-based simulation model of a supply chain in an emerging economy follows.

The first step in using the ABMS approach is to identify the agents and then model them. Agents could be business units like suppliers or individuals like customers. According to Macal and North (2005; 2006), agents have many characteristics, including behavior; memory; roles; attributes; states; resources; interaction with other agents and environment; rules to change their behavior/knowledge/memory/etc.; and capability to send and receive messages, which can be information, material, or cash. To apply such an approach to the GlobalResolve gel fuel supply chain, agents could include:

- Corn suppliers (located in or around the village)
- The production facility or facilities (located in the village)
- Transporters (individual trucks, individuals with no vehicles, distribution companies)
- Retailers (could be same as transporters or retail shops/stands or individual street sellers)
- Customers (individuals in the cities near the village who are end users)

Agent behavior (e.g., the behavior of a supplier responding to new orders or the quantity of gel fuel produced at one time) can be modeled by framing various probabilistic or binary decision rules obtained by observing the actual behavior of the entity.

Once the agents and agent behavior are defined, the structure elements, control elements, and the data, cash, and material flow of the supply chain must be identified. The structure elements for the supply chain model will be the agents themselves, and the control elements will be the rules and policies (e.g., what inventory levels of raw materials are kept at the production facility), that drive the supply chain. These rules trigger actions for the agents. The data, cash, and material flow of the supply chain are the messages that are transmitted between different agents, which can alter the memory, knowledge, and the state of the agents.

Finally, having modeled the agents, their characteristics, and the messages, we would then need to choose a proper modeling language and simulation software to build our model in the computer. One such modeling tool is the Unified Modeling Language (UML), which allows the use of a variety of helpful diagramming tools, including state diagrams. Other software options for developing ABMS models include packages dedicated to ABMS such as SWARM or NETLOGO or packages designed for conventional DES, such as ARENA or FLEXSIM, that can be modified use with ABMS (Macal and North 2005; Macal and

North 2006).

While using agent-based simulation could aid us in effectively evaluating various design alternatives for our supply chain, before we could actually build one, we need to have a feeling for the agent behavior so that we can develop appropriate rules and heuristics. Specifically, to better understand the behavior of retailers and customers in developing nations, we next discuss the importance of modeling bargaining behavior at various points in the supply chain and what a model of such behavior would need to include

Modeling Retail Bargaining Behavior in Developing Countries

Unlike most developed countries, most products in retail outlets in developing countries are not sold at a fixed non-negotiable price (Morris et al.1996). One explanation for such a market condition is that in developing/ underdeveloped nations, most retail channels are operated as informal businesses. The volume of sales is comparatively less when compared to big and formal businesses. Moreover, consumers are aware of the elasticity in prices and often bargain with the seller to get the best deal possible. Competition among sellers in an informal economy is intense, and as a result, sellers also dynamically change their margins to prevent the loss of a potential buyer (Varcin 2000). Consequently, understanding consumer behavior is an important factor for successfully modeling the gel fuel supply chain in Domeabra, Ghana.

A review of literature covering topics on bargaining and negotiations reveals a wide variety of factors that affect consumer behavior and vary across different cultures in different countries. For instance, one study investigates factors such as culture, age, and sex, and their influence on bargaining behavior using experimental results from India, Argentina, and the United States (Druckman et al. 1976). Additionally, Rossiter and Chan (1997) propose a model for predicting the effects of ethnicity on consumer behavior. Other factors that may impact the negotiation style of a particular population include time sensitivity, bargaining intentions, economic status, trust, need for cooperation, dependence, and level of coercion. The perception of fairness in business and the power wielded by one party over the other are additional factors that influence bargaining behavior in Ghana specifically.

The literature on modeling bargaining is often aimed at either confirming a hypothesis based on statistical analysis of data, or proving theoretical constructs such as those proposed by Nash (1950) or Bowley (1928). Lee (1998), for example, proves the hypothesis that bargaining behavior of American and Chinese customers can be explained by Azjen and Fishbein's behavioral intention model (1980). The bargaining literature does not, however, integrate the variations in supply, demand, and the behavioral pattern of the local demographic into a single structure for use in a prediction model. Such a structure is required to successfully build a model of a supply chain in an emerging economy where bargaining is prevalent. As a result, this research will aim to fill these gaps and focus on areas not previously addressed.

During future GlobalResolve field visits to Ghana, we plan to conduct designed bargaining experiments that will provide insight into the behavior of the particular demographic group under study (retailers and consumers at markets in an urban city in Ghana). Using this information, we plan to correlate how well the sample fits with a particular behavioral model. In essence, the model we plan to build will account for as many of the factors mentioned in the above paragraph as possible and will be used to predict the bargaining behavior of our target population. We hope that the model will also produce some quantitative output, including average negotiated price, percentage of failed negotiations, and variation in predicted versus actual data. The model can also employ certain game theory concepts to determine the strategy (or strategies) that a knowledgeable seller may employ to maximize his share of the bargain.

From a manufacturer's perspective, having concrete information about the average negotiated price

in a particular market is especially useful in devising pricing strategies. For example, if there is a high demand for the product and it is impossible to increase the supply, it could result in either the seller or the customers will be less inclined to bargain for that product. The manufacturer can utilize the model to fix an appropriate selling price that will maximize his profit without affecting the volume of sales (demand).

As part of this research, we will also try to answer questions such as:

- How does bargaining behavior correlate with the factors we had considered (time sensitivity, bargaining intentions, economic status, etc)?
- If we have a high-demand and low-supply situation or a low-demand and high-supply situation, will the seller or the buyer, or both, be less inclined to bargain?

Behavioral experts have built numerous models that can predict how humans respond to common situations (Sheth 1974). With a bargaining model such as we have described, we would hope to begin demonstrating how human behavior also influences business decisions (such as bargaining to settle on a particular price-quantity value).

The combination of ABMS and negotiation models can help in creating an accurate model of a supply chain in an emerging economy, which in turn helps in understanding the system, evaluating competing system configurations, and making better predictions. However, it remains difficult to implement any system configuration, as the information required to make informed business decisions resides in disjointed silos. Consequently, before successful supply chains can be developed in villages in emerging nations, a method for transmitting and storing information between supply chain parties must be identified. An area of growing research in developing nations is the use of inexpensive mobile phones for information transfer. The final portion of this paper discusses the implications of such work to a supply chain in an emerging economy.

The Role of Mobile Phones in Information Transfer

In most developing economies, the internet still represents an expensive form of communication, and hence is limited to the urban areas. In rural areas, where it is not feasible to expect significant investment to procure and install computer/internet systems, cheaply available mobile phones with basic functionalities can be a cost effective alternative for information exchange.

Specifically of interest to the gel fuel supply chain are mobile phones that do not require internet, but have basic applications such as voice messaging, cameras, and short messaging services (SMS). These mobile phones do not require internet access, are easily deployable, and are inexpensive. Additionally, mobile phones can be used to coordinate events in multiple locations (e.g., a village-based production area and an urban-based retailing area). Overå (2006) points out that the economic benefits of cell phones is particularly significant in complex supply chains where all parties have access to them.

While some work has been done (Javid and Parikh 2006; Parikh et al. 2007), there is not a great deal of published research on the idea of integrating the functions and capabilities of basic mobile phones specifically for a supply chain management system. Below is an initial list of functions within the basic supply chain that mobile phones could be used to employ:

- Announcement of the delivery of purchased inventory to the distribution warehouse
- Suppliers called to check on the status of orders
- Calls made to potential customers
- Broadcasts of important information sent to all supply chain employees

- Tracking goods through various supply chain locations

Utilizing mobile phones for supply chain activities may seem obvious, but the impact of effective communication is vital to the success of the operation, especially in locations where internet communication is not widely used. It would also not require significant changes to the model of supply chain operation. Though the exact results we expect to derive from the introduction of mobile phones into supply chains in emerging economies are still forming, the idea nevertheless presents a promising option that could capitalize on existing infrastructure at low cost.

Conclusions

This paper is exploratory in nature and is primarily aimed at documenting the initial groundwork for a much larger supply chain modeling project. Our next steps will involve collecting the relevant data necessary for further review and analysis. The paper demonstrates some of the unique issues present when modeling supply chains in emerging economies, such as the one involved with GlobalResolve's gel fuel project. While the gel fuel production facility is currently in place and functional, clearly much work remains before a complete and viable model for the supply chain is complete. Nonetheless, the information in this paper represents a step forward in resolving various logistical issues that are currently hindering full-fledged operations to produce and sell the fuel. Our hope is that when the model is complete, the gel fuel system will begin to create an income stream for the local village population and also provide a blueprint to replicate the success across various other regions in need of social entrepreneurship initiatives.

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