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Analysis of supplier selection policies for regional food systems using multi-agent simulation

by

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Program of Study Committee:
Caroline Krejci, Major Professor
Sigurdur Olafsson
Shweta Chopra

Iowa State University

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DEDICATION

I would like to dedicate this thesis to my mother for her continuous support. I would also like to dedicate this to my brother for his continuous motivation.

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NOMENCLATURE

RFSC	Regional Food Supply Chain
MAS	Multi-Agent Simulation
ABM	Agent Based Model
FFVs	Fresh Fruits and Vegetables

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ABSTRACT

Demand for regionally-produced food has seen tremendous growth in over the last decade, amid increasing consumer concerns over food safety, nutrition, origin, production practices and quality. Regional food systems provide economic support for small- and medium-sized farmers and help consumers become better-informed about their food, emphasizing the development of producer-consumer relationships and transparency with regard to production practices. In addition to these important social considerations, a sustainable and robust regional food system requires efficient and effective supply chain operations. However, most existing regional food supply chains (RFSCs) have not implemented appropriate supply chain management methodologies, and this has resulted in system-wide inefficiencies. Intermediated RFSCs, in which food is delivered to customers via a regional distributor, have recently become more prevalent. The role of the distributor, or "food hub", is to provide a platform through which producers can efficiently and conveniently connect with customers. The food hub is also often responsible for ensuring transparency and facilitating information sharing and communication between producers and customers. Therefore, for a successful intermediated RFSC it is essential that the food hub manager selects his/her producers properly.

In this thesis, the impacts of variety of supplier selection policies on regional food system are discussed. We discuss what performance metric a RFSC should consider while evaluating the farmers. We also discuss the objectives of the food hub and the farmers. The food hub managers that we have interviewed have indicated that they do not have formal supplier selection policies. Instead, they randomly select suppliers that they believe will be

able to fulfill their current demand. There is very little existing research on how to model the problem of supplier selection for regional food systems. In general, however, the literature suggests that multi-agent simulation (MAS) is a useful tool for studying supply networks and supply chain management methodologies. MAS is an approach to modeling and understanding complex systems that are composed of autonomous and interacting agents. Because a multi-echelon supply chain is a very complex social system, it is appropriate to use MAS to simulate supply chain behavior over time. Specifically, supply chains that are decentralized in command and control (such as RFSCs) are more appropriately captured using MAS techniques, rather than more traditional operations research methods. Many researchers have described supply chains by their constituent actors, activities, interdependencies, goals, and objectives, and they argue that systems possessing these components and structures are well-suited to analysis using MAS techniques. To study this system, we developed an agent-based model of a theoretical regional food system in NetLogo.

CHAPTER 1

GENERAL INTRODUCTION

Regional Food

Food is the source of energy for every human being. It is generally said, good food is essential for overall development of human body and mind. That said, it is important to avoid waste and loss of good quality food. Jedermann (2014) in his research present how food losses which are roughly one-third of food produced for human consumption, of which 15% are during distribution of fresh fruits and vegetables (FFVs). Gunasekaran (2001) identifies that US industry is wasting $30 billion annually due to poor coordination among supply chain partners. Our research is a step towards identifying how this losses can be reduced.

In Asia, 'fresh' food means 'as close as possible to the consumer' (Cadilhon 2006). There is no specific definition of regionally produced food, however one set of definition is essentially based on geography i.e. distance between the consumer and the producer (Jones 2004). Another definition is described as emotional reach, i.e. based on the consumers' perspective what is local. One more definition as defined by the Alliance for Better Food and Farming describes local food as one which meets criteria of embracing not only geographical distance but also other specified criteria like environmental safety, animal welfare, proper employment, fair trade and cultural conditions (Jones 2004).

Regional food system is emerging because consumers are becoming aware of the vulnerabilities of Industrial food system such as decrease in crop diversity and its dependency on fertilizers and pesticides for crop productivity (Stroink 2013). Regionally produced food is one of the way of supplying healthier and more nutritious food (Epperson 1999). Demand for regionally-produced food has increased tremendously in the past decade

as consumers have become increasingly aware of the benefits of supporting regional food systems. Consumers' reasons for buying regional food vary widely. Jones (2004) mentions the increase in demand of regionally produce food is due to various reasons like food scarcity and increasing consumer concern about food safety. Other typical reasons include: a desire to save money on groceries, a belief that regional food is fresher, safer, and/or more nutritious than conventionally-produced food, concerns about the environment and the treatment of farm workers, and a desire to support the local economy and establish connections with the people who produced their food (Brown 2002; Brown 2003; Wolf 2005). This demand growth has been a boon to small- and medium-scale farmers, who can benefit from higher prices and fewer restrictions on volume, compared with sales through mainstream distributors. However, they have also begun to discover that new market and distribution channels will be necessary to efficiently and effectively support this demand, while continuing to support the values that consumers seek (Krejci and Beamon 2014). In particular, many farmers are challenged by a lack of distribution infrastructure which would provide them with better access to retail, institutional, and commercial food service markets where demand for regional food is substantial (Barham 2012).

Food Hub

As consumers are looking for various new options to buy FFVs, food hubs are emerging as a new regional food system (Stroink 2013). A new novel concept of a regional aggregator, or "food hub" has emerged. Food hubs is defined as community based initiative to link producers and consumers (Stroink 2013). A food hub provides smaller-scale farmers a platform for aggregating their products and distributing them to institutional and retail buyers

who would like to buy regional food at larger volumes than traditional farmers' markets can support. By providing a single point of sale, a food hub can reduce farmers' operational costs and enable them to be more profitable. Although their missions, strategies, and structures can vary widely, nearly all food hubs offer a combination of production, distribution, and marketing services that allows smaller-scale farmers to gain entry into new and additional markets that would be difficult or impossible to access on their own (Barham 2012). Food hubs also benefit customers by providing them with a single point of purchase for consistent and reliable supplies of source-identified products from regional producers.

Although regional food hubs are a great idea and have become very popular (there are currently over 200 food hubs in the U.S.) (Fischer 2013), many of them have struggled to make ends meet. Some of the most commonly-cited challenges faced by food hubs are insufficient infrastructure for efficient distribution, an inability to successfully match supply and demand, and an inability to meet customer requirements for consistent year-round volumes and high quality (Goodspeed 2011; Bittner 2011; Vogt 2008; Gregoire 2005). Efficiently meeting customer requirements is of particular importance, and food hubs must rely heavily upon their suppliers to make this happen. Therefore, a robust supplier selection and assessment strategy is critical to food hubs' long-term success.

Farmer Selection

There are many studies in the domains of manufacturing and service industries that recommend that distributors periodically and systematically evaluate supplier performance in order to retain those suppliers who meet their requirements in terms of multiple performance criteria that are aligned with the organization's values and objectives (Mummalaneni 1996).

Although there is very little research on the problem of supplier selection and evaluation for regional food hubs, it would seem that they should be able to follow the same guidelines as those that are recommended for other industries. In reality, however, food hubs tend to use ad-hoc heuristics to select and evaluate their farmers (suppliers), and they do not systematically track supplier performance over time. A major reason for this is that food hubs typically lack the infrastructure, personnel, and financial resources to support a supplier management program. However, they also face challenges that are unique to the regional food domain. For example, regional food systems are typically supported by a large number of small, independent producers who have widely variable objectives, preferences, and abilities, and they greatly value their autonomy. Another challenge is that regional food hubs are typically motivated not only by traditional supply chain metrics (i.e., maximizing profits), but also by social concerns (e.g., supporting regional employment). This concern for overall social welfare of regional producers is typically rooted in personal values, a desire to maintain a strong and diverse regional supply base, and/or government incentives in support of regional economic development. One of the many challenges that food hubs face is determining appropriate policies for supplier management that balance these two (often conflicting) objectives. For example, food hub managers would like to know how to determine the ideal number of producers they should work with for each product type to minimize risk, provide customers with sufficient selection, and provide sufficient revenues for the producers. These managers also have concerns about developing and managing quality assurance policies that satisfy their customers but are not overly burdensome to the producers. With per-capita consumption of FFVs continuously rising, and the number of small- and medium-sized farmers declining, it is important to address the chronic issue of

small- and medium-sized farmers' sustainability systematically and supplying good quality of FFVs.

Multi-Agent Simulation

As a result, the supplier selection and evaluation problem in regional food systems is very complex. Traditional modeling tools are inadequate for the analysis of complex systems like food supply networks (North 2007). Multi-agent simulation is a particularly appropriate modeling methodology for studying the dynamics among the many autonomous, heterogeneous, and interacting agents the regional food chain (Axtell 2000). In this paper, we describe a multi-agent simulation model of a regional food supply network, in which farmer agents and a food hub agent interact, gather feedback, and adapt accordingly over time. This virtual system can be used to test the impact of various supplier selection policies on the performance of the system and its structural development over time.

In this research, we carry forward the work started by Bora and Krejci (2015) to develop additional supplier selection policy (contract based supplier selection). This model also evaluates the performance metric from all the aspects of supply chain, i.e. delivery parameter is added to the evaluation which was missing in the model of Bora and Krejci (2015). A sensitivity analysis is performed by changing various parameters like transportation cost, weightage on components of performance metric and negotiation success rate. This sensitivity analysis will help understand the model as well as the policies in a better way and enable the food hub manager to take necessary decisions.

Thesis Organization

Chapter 2 details the need for such research, the literature review of supply chain, supplier selection policies and multi-agent simulation. Then the multi-agent simulation model used in the research is described in details. Following the model description, analysis of the results of the three policies used in done as per the RFSC parameters. A sensitivity analysis is performed by changing various parameters like transportation cost, weightage on components of performance metric and negotiation success rate. Chapter 3 provides with general conclusions of the study as well as the future direction in this research.

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CHAPTER 2

ANALYSIS OF SUPPLIER SELECTION POLICIES FOR
LOCAL FOOD SYSTEMS USING AGENT BASED SIMULATION

Abstract

Demand for regionally-produced food has seen tremendous growth in over the last decade, amid increasing consumer concerns over food safety, nutrition, origin, production practices, and quality. Regional food systems provide economic support for small- and medium-sized farmers and help consumers become better-informed about their food, emphasizing the development of producer-consumer relationships and transparency with regard to production practices. In addition to these important social considerations, a sustainable and robust regional food system requires efficient and effective supply chain operations. However, most existing regional food supply chains (RFSCs) have not implemented appropriate supply chain management methodologies, and this has resulted in system-wide inefficiencies. Intermediated RFSCs, in which food is delivered to customers via a regional distributor, have recently become more prevalent. The role of the distributor, or "food hub", is to provide a platform through which producers can efficiently and conveniently connect with customers. The food hub is also often responsible for ensuring transparency and facilitating information sharing and communication between producers and customers. Therefore, for a successful intermediated RFSC it is essential that the food hub manager selects his/her producers properly. However, food hub managers typically indicate that they do not employ formal supplier selection policies. Instead, they randomly select suppliers that they believe will be able to fulfill their current demand.

. There is very little existing research on how to model the problem of supplier selection for regional food systems. The literature suggests that multi-agent simulation (MAS) is a useful tool for studying supply networks and supply chain management methodologies. MAS is an approach to modeling and understanding complex systems that are composed of autonomous and interacting agents. Because a multi-echelon supply chain is a very complex social system, it is advantageous to use MAS to simulate supply chain behavior over time. Specifically, supply chains that are decentralized in command and control (such as RFSCs) are more appropriately captured using MAS techniques, rather than more traditional mathematical modeling methods.

This thesis describes the development and application of a multi-agent simulation model of a theoretical regional food system intermediated by a food hub to test the impacts of three different supplier selection policies on regional food system performance. Both the performance of the individual RFSC members and the overall RFSC performance are captured. Performance is measured with respect to multiple (and sometimes conflicting) supply chain metrics, including quality, delivery, price, the relationship between the food hub and the supplying farmers, and farm size distribution. The model is also used to determine the extent to which each of the three supplier selection policies would help small- and medium-sized farmers become more economically sustainable

Introduction

Demand for regionally-produced food has increased tremendously in the United States over the past decade as consumers have become increasingly aware of the benefits of supporting regional food systems. There is no single specific definition of regionally-produced food.

However, one typical definition is based on geography, i.e., the distance between the consumer and the producer (Jones 2004). Another definition is based on emotional reach, i.e. consumers' perspective on what is local (Jones 2004). Another definition by the Alliance for Better Food and Farming describes local food as meeting criteria of embracing not only geographical distance but also other specified criteria like environmental safety, animal welfare, proper employment, fair trade and cultural conditions (Jones 2004). In Asia, 'fresh' food means 'as close as possible to the consumer' (Cadilhon 2006).

Consumers' reasons for buying regional food vary widely. Consumers are becoming aware of the vulnerabilities of the conventional industrial food system, such as decreases in crop diversity and a dependency on agrochemicals (i.e., fertilizers and pesticides) for crop productivity (Stroink 2013). Regionally-produced food is also perceived as a way of supplying healthier and more nutritious food (Epperson 1999). The increase in demand for regionally-produced food also corresponds to consumer concerns regarding food scarcity and safety (Jones 2004). Other typical reasons include: a desire to save money on groceries, a belief that regional food is fresher than conventionally-produced food, concerns about the environment and the treatment of farm workers, and a desire to support the local economy and establish connections with the people who produced their food (Brown 2002; C. Brown 2003; Wolf 2005). Additionally, roughly one-third of the food produced for human consumption food is lost as food waste, partly as a result of long-distance food supply chains (Jedermann 2014). US food industry is wasting $30 billion annually due to poor coordination among supply chain partners (Gunasekaran 2001). Regionalizing food distribution may help to mitigate such losses.

This growth in demand for regional food has been a boon to small- and medium-scale farmers, who can benefit from higher prices and fewer restrictions on volume, compared with sales through mainstream distributors. However, they have also begun to discover that new market and distribution channels will be necessary to efficiently and effectively support this demand, while continuing to support the values that consumers seek (Krejci and Beamon 2014). In particular, many farmers are challenged by a lack of adequate distribution infrastructure that would provide them with better access to retail, institutional, and commercial food service markets where demand for regional food is substantial (Barham 2012).

As producers and consumers increasingly seek new and more convenient options for selling and purchasing regionally-produced food, a novel concept of a regional aggregator, or "food hub", has emerged. A food hubs is defined as a community-based initiative to link producers and consumers (Stroink 2013). A food hub provides smaller-scale farmers a platform for aggregating their products and distributing them to institutional and retail buyers who would like to buy regional food at larger volumes than traditional farmers' markets can support. By providing a single point of sale, a food hub can reduce farmers' operational costs and enable them to be more profitable. Although their missions, strategies, and structures can vary widely, nearly all food hubs offer a combination of production, distribution, and marketing services that allows smaller-scale farmers to gain entry into new and additional markets that would be difficult or impossible to access on their own (Barham 2012). Food hubs also benefit customers by providing them with a single point of purchase for consistent and reliable supplies of source-identified products from regional producers.

Regional food hubs have significant potential and have become very popular - there are currently over 200 food hubs in the U.S. (Fischer 2013). However, most of them have struggled to make ends meet. Some of the most commonly-cited challenges faced by food hubs are insufficient infrastructure for efficient distribution, an inability to successfully match supply and demand, and an inability to meet customer requirements for consistent year-round volumes and high quality (Goodspeed 2011; Bittner 2011; Vogt 2008; Gregoire 2005). Efficiently meeting customer requirements is of particular importance, and food hubs must rely heavily upon their suppliers to make this happen. Therefore, a robust supplier selection and assessment strategy is critical to food hubs' long-term success.

There are many studies in the domains of manufacturing and service industries that recommend that distributors periodically and systematically evaluate supplier performance in order to retain those suppliers who meet their requirements, in terms of multiple performance criteria that are aligned with the organization's values and objectives (Mummalaneni 1996). Although there is very little research on the problem of supplier selection and evaluation for regional food hubs, it would seem that they should be able to follow the same guidelines as those that are recommended for other industries. In reality, however, food hubs tend to use ad-hoc heuristics to select and evaluate their suppliers, and they do not systematically track supplier performance over time. A major reason for this is that food hubs typically lack the infrastructure, personnel, and financial resources to support a supplier management program. They also face challenges that are unique to the regional food domain. For example, regional food systems are typically supported by a large number of small, independent producers who have widely variable objectives, preferences, and abilities, and they greatly value their autonomy. Another challenge is that regional food hubs are typically motivated not only by

traditional supply chain metrics (e.g., maximizing profits), but also by social concerns (e.g., supporting regional employment). This concern for overall social welfare of regional producers is typically rooted in personal values, a desire to maintain a strong and diverse regional supply base, and/or government incentives in support of regional economic development. One of the many challenges that food hubs face is determining appropriate policies for supplier management that balance these two (often conflicting) objectives. For example, food hub managers would like to know how to determine the ideal number of producers they should work with for each product type to minimize risk, provide customers with sufficient selection, and provide sufficient revenues for the producers. These managers also have concerns about developing and managing quality assurance policies that satisfy their customers but are not overly burdensome to the producers. With per-capita consumption of regional food continuously rising, and the number of small- and medium-sized farmers declining, it is important to systematically address the chronic issue of small- and medium-sized farmers' sustainability, as well as the availability of good-quality regionally-produced food.

Thus the supplier selection and evaluation problem in regional food systems is very complex. Traditional modeling tools are inadequate for the analysis of complex sociotechnical systems like food supply networks (North 2007). By contrast, multi-agent simulation is a particularly appropriate modeling methodology for studying the dynamics among the many autonomous, heterogeneous, and interacting agents in the regional food chain (Axtell 2000). In this paper, we describe a multi-agent simulation model of a theoretical regional food supply network, in which farmer agents and a food hub agent interact, gather feedback, and adapt accordingly over time. This virtual system can be used

to test the impact of various supplier selection policies on the performance of the system and its structural development over time.

This thesis builds on the preliminary work of Bora and Krejci (2015). A multi-agent simulation will be described that was developed and used to test the effects of three different supplier selection policies on the performance of a regional food system. In the following sections, we present the literature review of supply chain, supplier selection policies and multi-agent simulation. Then the multi-agent simulation model used in the research is described in details. Following the model description, analysis of the results of the three policies used in done as per the RFSC parameters. A sensitivity analysis is performed by changing various parameters like transportation cost, weightage on components of performance metric and negotiation success rate. This sensitivity analysis provides with some insights about the model and showcases the robustness of the model. The results are followed by conclusions. We expect the results and conclusions will help the food hub managers and researchers in RFSC take appropriate measures for the success of local food system. It should be noted that regional food and local food are used interchangeably throughout this thesis. Also suppliers, producers and farmers are used interchangeably throughout the thesis.

Literature Review

In this section literature review of supply chain and supplier selection policies is presented. A literature review of multi-agent simulation is also presented.

Supply Chain Management

Supply chains exist in virtually every industry, including manufacturing, services, and distribution. Management of the supply chain is not an easy task, due to the multiple actors and activities involved, including procuring raw materials, transforming them into intermediate subassemblies and final products, and then delivering these products to the end customers (Strader, 1998). A supply chain is a system of suppliers, manufacturers, distributors, and customers linked together via two types of flow: 1) feedforward flow of materials and 2) feedback flow of information (Towill, 1992). The feedforward flow consists of delivering products or service while the feedback flow consists of reviews, payment, and reports. This feedback loop gives insights into the customers' requirements and values. Figure 1 shows a general supply chain structure.

A supply chain has also been defined as "a network of various autonomous or semiautonomous business entities collectively responsible for procurement, manufacturing and distribution activities" (Swaminathan, 1998). These entities include the suppliers, contractors, buyers, distributors, and retailers who are collectively responsible for supply chain activities (Jiao, 2006). The interconnections among these entities make modern supply chains complex, and if these interconnections are not properly managed, they can lead to suboptimal overall supply chain performance. For example, the "bull-whip effect" can significantly increase the amount of inventory that is held across the supply chain because of the distortion of information that is passed from one echelon to another via feedback loops (Schieritz, 2003).

The literature suggests multiple strategies to improve the efficiency and effectiveness of the supply chain (Van der Vorst, 2009). These strategies include redesigning supplier

selection policies, reducing lead times, improving delivery methods, creating information transparency, and finding ways to coordinate and simplify logistics. However, to understand the impacts of such strategies, supply chain performance must be measured. By measuring the performance of the supply chain, managers can make appropriate decisions to change policies in order to achieve their objectives. Also, measuring supply chain performance gives managers a competitive advantage, since they know where they stand. In recent years, many firms have realized the potential of effective supply chain management; however, they lack

Figure 1: Supply Chain System

the necessary insights for the development of effective performance measures and metrics (Gunasekaran, 2001). Swaminathan (1998) classifies supply chain performance into two broad categories: qualitative and quantitative. Beamon (1998) also supports this classification of performance and states that the establishment of appropriate supply chain performance measures is critical to their success, by allowing managers to compare competing alternative systems and improve the efficiency of the existing systems. Qualitative performance measures include customer satisfaction, flexibility, and supplier performance (Beamon, 1998;

Swaminathan, 1998). Customer satisfaction depends on quality, cost, delivery, and overall responsiveness of the entire supply chain with respect to service and products. Flexibility is the degree to which the supply chain can respond to uncertain demand and supply. Supplier performance measures the performance of suppliers with respect to quality, cost, delivery and relationship or response (i.e., the characteristics of customer satisfaction). Quantitative performance measures include supply chain costs, profits, customer response times, and lead times. Customer response time is defined as the time taken by the supplier to adapt to changes in the demands of the customer. These measures will help to test and reveal various strategies for the improvement of the supply chain and to achieve the objectives of the constituent firms (Gunasekaran, 2001).

Supplier Selection

The revolution in supply chain management in the 1990s was driven by changes in coordination among suppliers and buyer procurement policies (Strader, 1998). Coordination requires communication within and across all supply chain echelons (Malone, 1991). Buyers, production managers, suppliers, accounts offices, truck drivers, and operators must all coordinate their activities in order for the supply chain to function efficiently and effectively. Overall supply chain performance depends upon the performance of the individual suppliers and their willingness to coordinate with one another (Swaminathan, 1998). Such coordination requires the timely sharing of accurate information among supply chain actors, which is generally embedded in all supply chain management programs (Lee H. L., 2000). For example, by sharing point-of-sale information with its suppliers, a buyer can help to counter the "bullwhip effect". Other useful information can be shared with suppliers in order to avoid

confusion and maintain harmony, including the definition of quality, applicable quality standards, and packaging requirements.

The ability for supply chain actors to effectively coordinate their activities stems from procurement activities. Buyer procurement activities include searching for a supplier, selecting a supplier, negotiating with the supplier, and completing the transaction, followed by feedback or a performance rating. Supplier performance is critical to buyers and enables them to use the supply chain for competitive advantage (Krause, 2000). Once the suppliers are selected, they have a lasting impact on the competitiveness of the entire supply chain, as they tend to remain fixed in long-term buyer-supplier relationships (Choi, 1996). Therefore selection and periodic evaluation of suppliers are two of the most significant processes of a supply chain system since they define the motives of the buyers and help the buyers evaluate current suppliers and potential suppliers (Mummalaneni, 1996). Beamon (1998) classifies supplier performance as the consistency of suppliers in terms of quality and delivery. Thus, selecting suppliers does not only depend upon low cost, but also a variety of other important factors, such as quality, delivery, and location (Mummalaneni, 1996; Swaminathan, 1998; Choi, 1996). Different suppliers have different sets of constraints and objectives (Swaminathan, 1998). This makes the job of the buyer very difficult, since he has to make difficult decisions with respect to tradeoffs between various elements of supplier performance. Therefore to make the correct decisions, buyers must monitor supplier performance on basis of quality, delivery, cost, flexibility and reputation (Mummalaneni, 1996). As managers try to improve supply chain performance, it is critical to understand the impact of supplier selection policies on the managers' own organizations, as well as their suppliers (Swaminathan, 1998).

Supplier Selection Policies

Supplier selection is a part of the forward and feedback loop shown in Figure 1. However, supplier selection itself is also a loop. Figure 2 represents the loop of supplier selection which consists of six steps (Hong, 2005). The first step is to search for the suppliers which supply the required product. The second step is to shortlist the suppliers with respect to the objectives of the purchasing organization and its supplier selection policies. The third step is to interact with the suppliers and set the contractual terms. The fourth step is to complete the transaction. The fifth step is to evaluate the supplier and the entire procurement process. Finally, the sixth step is to give feedback to the suppliers about the procurement process.

The findings of Choi, et al. (1996) are consistent with those of many other researchers in terms of how supplier selection policies should be developed. The authors find through their study that: 1) selecting suppliers based on the potential for a long-term relationship is very important, 2) price is much less important than quality and delivery metrics, and 3) consistency in quality and delivery are the most important criteria in selecting suppliers. They also find that by collaborating with suppliers to better understand the demand and improve delivery and product quality, buyers can improve their relationships with suppliers and achieve higher customer satisfaction. It is necessary for purchasing managers to have policies in place to support the consistent selection of high-performing suppliers in order to implement successful supply chain management systems (Choi, 1996). Supplier selection policies can help to reduce negotiation time, maintain a consistent set of suppliers, eliminate non-value-added costs, and achieve common objectives for an efficient supply chain (Van der Vorst, 2009). Once supply chain management policies, including supplier selection, are

in place, buyers and suppliers can collaborate in order to achieve individual organization and overall supply chain objectives (Choi, 1996).

Figure 2: Process flow of supplier selection

Supplier selection depends upon the evaluation of existing and potential supplier performance. There are many studies in the domains of manufacturing and service industries that recommend distributors periodically and systematically evaluate suppliers' performance, and this is a common practice in the automotive and electronic industries across the globe (Choi, 1996). Performance evaluation ensures that suppliers that consistently meet requirements aligned with the values and objectives of the organization are retained. The evaluation also helps buyers to remain competitive while selecting suppliers in the future. Supplier selection policies should be designed in a way to improve supplier performance and capabilities (Krause, 2000).

The literature on supplier selection includes different frameworks for supplier evaluation and performance. For example, Krause (2000) classifies the strategies to evaluate supplier performance as internalized or externalized activities. An internalized supplier

selection strategy is defined as selecting suppliers in which the buying firm has direct involvement or represents a direct investment in terms of production, purchasing capital, or process setup. An externalized supplier selection strategy is defined as selecting suppliers from the external market and encouraging competitiveness to improve performance. This thesis is focused on externalized supplier selection strategies, wherein the buying firm has neither direct involvement nor investment in the suppliers and all of the suppliers behave autonomously.

Krause (2000) also classifies selection strategies into three categories. With a competitive pressure strategy, the buying firm applies the competitive force of the market by requesting suppliers to bid and select suppliers with low prices. A supplier assessment strategy: involves the buying firm's evaluation of suppliers' quality, delivery, cost, reliability, and flexibility in order to select a supplier. With a supplier incentives strategy, the buying firm provides incentives for the best performing suppliers and gives them priority or assurance of future business. This strategy is designed to motivate the suppliers to continuously improve their performance (Krause, 2000).

Other methods of selecting suppliers are described as data envelopment analysis, clustering analysis, and case-based reasoning (De Boer, 2001). However, these methods are only used for screening suppliers and not for final selection. Final selection can be done using the linear weighting method and the mathematical programming (MP) method (Hong, 2005). The linear weight method assigns weights to the variables according to their highest importance. The main characteristic of this method is that it helps the buyer to identify the strengths and weakness of a supplier by comparing them with other suppliers (Hong, 2005). The MP method allows the buying firm to formulate a mathematical objective function in

order to select suppliers. This model maximizes certain variables (e.g., quality and quantity) and minimizes others (e.g., cost and delivery delays) to support supplier selection decisions.

Another method used during supplier selection is that of fixed contracts. Contracts can help buyers to mitigate risks by ensuring regular supply in terms of quality, quantity and time, while at the same time helping suppliers earn additional profits (Lee et al, 1999; Van der Vorst, 2009).   There are many supply chain contract models, including quantity flexibility (QF), backup agreements, buy back or return policies, and revenue sharing (RS) contracts (Giannoccaro, 2004). In QF models the buyer commits to purchase a minimum quantity from the suppliers. The backup agreement helps the buyer to reduce risk of demand uncertainty by making a backup supply available by paying a certain fixed cost. Under a return policy contract, the buyer can return the products to the suppliers if there is insufficient demand. Such contracts are possible in merchandise and apparel industries but are rarely seen in industries in which the product has a fixed shelf life (e.g., fresh food). Under the RS model, the buyer shares a specified amount of profit with its suppliers. This model is similar to the supplier incentive strategy. Also the RS and the return policy are similar in the sense that both types of contracts realize the potential of the demand (Cachon, 2005). Proper contract design can improve profits and performance of the entire supply chain and can act as an incentive to suppliers to participate in the supply chain (Giannoccaro, 2004).

Supply Chain Management for Regional Food Supply Chains

Many researchers have mentioned that food supply chains in general and regional food supply chains specifically are not as developed as the supply chain systems of automotive or electronic industries (Ahumada, 2009). Thus there is a need for more research on regional

food supply chains (RFSCs) in order to make them on par with the state-of-the-art techniques that are commonly used in other modern supply chains. One reason that these practices cannot always be directly used by RFSCs is that they exclusively focus on buying firms' criteria and ignore the suppliers' objectives (Choi, 1996). Another reason for difficulties in implementing supply chain practices in RFSCs is due to market uncertainties and shorter product life (Ahumada, 2009). However, RFSCs have recently gained more attention due to the growing demand of regional food, government regulation, public concerns over food they consume, and the need for better quality and diverse food (Marsden, 2000). With RFSCs, the long and complex structure of industrial food chains is replaced with short consumer/producer-oriented and transparent supply chains. The sophistication required to compete with the conventional supply chain makes it important for RFSCs to adopt the supply chain management techniques that have been successfully implemented in the manufacturing sector (Ahumada, 2009).

However, RFSCs possess unique attributes that make them different from other supply chains. In RFSCs, farmers are very self-directed and do not necessarily buy into distributors objectives readily. Food buyers and farmers are equally powerful and sometimes have conflicting objectives, which makes the decision making decentralized (Swaminathan, 1998). This autonomous farmer behavior makes it challenging to model an RFSC. Also, the emphasis on quality in the marketing strategies of fresh food and vegetables is enormous in RFSCs, compared with other supply chains (Berdegué, 2005; Van der Vorst, 2009). The RFSC also redefines producer-consumer relationships to emphasize the importance of trust, transparency, and traceability (Marsden, 2000).

Research on supplier selection in food supply chains exists in the literature. For instance, Hong et al. (2005) developed a mixed integer model to select suppliers in the agriculture industry in Korea. Their model had three core characteristics: 1) selected suppliers maintained long-term relationship with buyers unless their performance was unsatisfactory, 2) suppliers satisfying ideal procurement conditions were selected more often and 3) the model was dynamic, meaning that it considered changes occurring in supply and procurement policies over time. Berdegué et al. (2005) state that food buyers today are shifting their procurement policies from buying from traditional wholesalers and wholesale markets to specialized farmers and centralized distribution centers to ensure consistent suppliers and a high standard of quality control. Using a systematic supplier selection system leads to the implementation of quality standards, thereby improving quality across the food supply chain (Berdegué, 2005). In particular, the promise of contracts as a result of supplier selection can act as an incentive for farmers to move to larger markets that offer better prices. This can help them to improve their quality and invest in quality control (Berdegué, 2005). A policy of selecting farmers based on performance has been shown to help to improve overall quality in a food supply chain (Bora and Krejci, 2015). Zheng et al. (2014) claim that adopting best practices (e.g., industrial clusters) in RFSCs would help reduce supply chain costs. These reductions in supply chain costs may help reduce the high costs of products supplied through RFSCs and allow them to be competitive in a market that is dominated by conventional food supply chains (Epperson, 1999).

Marsden et al. (2000) describe three categories of RFSCs: 1) face-to-face, wherein the consumer purchases directly from the farmer (e.g., a farmers' market); 2) spatial proximity, where the farmers sell through retail units but only in the local market (e.g., food hubs); and

3) spatially extended, wherein the farmers export to different regions. The focus of this thesis is on spatial proximity. Figure 3 gives a brief overview of an RFSC that is intermediated by a regional food hub. A regional food hub is an aggregator cum distributor of regionally grown produce.

Figure 3 : Regional Food Supply Chain (RFSC) System

Food hub managers often prefer to select small- or medium-sized farmers, often because large farmers and wholesalers are unable to meet the specific and strict quality standards of regional food consumers (Berdegué, 2005). Selecting a large farmer also makes the food hub vulnerable in the negotiation process (Berdegué, 2005).

Caswell (1998) states that adopting supply chain will not only improve the quality of the food but will also reduce waste and transaction costs for farmers, distributors, and customers. The adoption of systematic farm-level quality assurance procedures and measures could also confer significant marketing advantages and increase consumer confidence in RFSCs

(Caswell, 1998). According to Caswell (1998), ensuring quality is easier in RFSCs than it is in long conventional food supply chains, and it involves lower transaction costs.

Challenges in Regional Food Supply Chain Management

The challenges in RFSC management can be classified into two very broad categories: quality and procurement and delivery. This section describes the challenges mentioned by various researchers in the field of RFSC management.

Quality and Procurement

Research in the field of RFSC performance and metrics is rather limited (Bourlakis, 2014). There is also very little existing research on RFSC procurement practices and supplier selection methods (Hong, 2005). Supply chain quality assurance is a constant challenge for the food hub managers (Ting, 2014; Van der Vorst, 2009). In RFSCs, supplier quality performance varies depending upon the practices adopted by the farmer and also on the reviews by consumer. The response on quality is quick so it can be incorporated into next procurement cycle. Thus there is need for research in procurement and farmer selection in RFSC. (Marsden, 2000).

Bourlakis et al. (2014) mention that in RFSCs, information that supports traceability, trust, and transparency is more important to the consumer than their distance from the farmer or the method of product handling. It is this information that demands premium prices and also differentiates the RFSC from conventional FSCs. Unlike conventional chains, providing information along with the products is the key preposition of RFSCs (King, 2010). Bosona et al. (2011) mention that one of the reasons for increasing demand for local food is traceability of the source of the food. Brannen et al. (2013) mention that one of the advantages of food

hubs and RFSCs is traceability; information about product sourcing and production methods is easily tracked. Network integration can helps to increase the quality of local food products through improving the traceability of food origin. An integrated traceability system provides an added layer of food security (Bantham, 2003). However, the efficiency of product traceability depends on information connectivity (Engelseth, 2009).

Delivery

Delivery and costs related to transportation and distribution are critical for the economic and environmental sustainability of the RFSC (Bourlakis, 2014). Through reduced transport distances, RFSCs offer a means of improving food system environmental sustainability, which is the focus of existing research (Van der Vorst, 2009). With continuous increases in demand and the number of famers involved in RFSCs, supply chain complexities are increasing. In such multi-layered complex supply chains, there is a need for structured methodology to address challenges in RFSCs (Ting, 2014). It is necessary for farmers to follow supply chain best practices to be sustainable in today's challenging and consumer-oriented market (Traoré, 1998). Agustina et al. (2014) mention that the biggest challenge for RFSCs is to deliver products on time and at a low cost without compromising farmer the profits. Norbis et al. (2008) highlight various challenges related to transportation, such as capacity shortage, growth in domestic and international sales, empty backhauling, shipment size, security concerns, contamination concerns, and environmental and energy concerns, suggesting a need for more research on transportation choice. Gunders et al. (2012) summarizes the reasons for food losses during distribution, and attributes it largely to improper handling and inconsistent refrigeration; better infrastructure and training is required

to avoid such losses. However, Mundler et al. (2012) find that conventional food supply chains have a higher rate of energy consumption than the majority of RFSCs.

Disorganization, a lack of systematic supply chain management structures, and numerous false starts and experiments are the reasons for failures of many food hubs (Stroink, 2013). There are few state-of-the-art models for RFSC management, and there is a need for more research in this area in order for them to be on par with non-food industries (Ahumada, 2009). Since today's RFSCs are relatively new, their logistics experience is still being developed, and they have significant room for further performance improvement.

In order to be successful in RFSC, it is necessary for food hubs to formulate policies related to farmer selection (Ahumada, 2009). Currently, the most preferred tools for supplier selection in RFSCs are the coordination methods, although contracting arrangements are also gaining popularity. According to Bosona et al. (2011), clustering and logistics network integration approaches have shown positive improvements in logistics efficiency, environmental impacts, traceability of food quality, and the potential market for local food producers.

Modeling Methods for RFSC Management

Modeling is a way to recreate a real system on the computer and solve the problems of the real world (Borshchev, 2004). There are various methods used to model supply chain systems, including simulation, which allows for systematic testing (Van der Vorst, 2009; Schieritz, 2003). Using simulation is cost-effective and can enable useful investigations and system improvement implementations without being confronted with real-world consequences (Schieritz, 2003; Towill, 1992).

Computer-based simulations have been commonly used to understand supplier-buyer relationships (Giardini, 2008). For example, the AgriPoliS model has been used to model agricultural supply chains (Matthews, 2007). AgriPoliS is an aggregated optimization model which is implemented using object-oriented programming languages. System dynamics is another tool used by researchers to understand supply chain systems with the help of ordinary differential equations (Schieritz, 2003). The drawback of system dynamics is that the structure of the supply chain is pre-determined, which is not generally applicable to real supply chains and especially to RFSCs (Schieritz, 2003). Towill et al. (1992) advocate using industrial dynamic simulation to evaluate the performance of a general supply chain systems. A discrete event simulation model, ALADINTM, has been developed and used to perform analysis on logistics, sustainability and food quality (Van der Vorst, 2009). However, discrete event simulation is mostly used for transportation and logistics rather than analysis of quality and sustainability (Van der Vorst, 2009).

Multi-Agent Simulation

Multi-agent simulation (MAS) is a relatively new method to model systems with agents who are autonomous and interact with each other (Macal & North, 2009). MAS models have gained popularity because they can: 1) solve complex problems, 2) capture autonomous human behaviors and interactions, 3) use stochastic data, and 4) be used to find satisfactory solutions (Siebers, 2010). Wooldridge (2009) defines agents as computer systems that are capable of independent action. Ferber (1999) in his book on Multi-Agent System defines agents as autonomous physical or virtual entities with the skills to achieve their objectives that can act, perceive their environment, and communicate with others. MAS encodes the

behavior of agents in simple rules so that we can observe the results of these agents' interactions (Wilensky, 2015). An agent performs actions and makes decisions in order to achieve its objectives without being explicitly asked to do so.

However, for an agent to successfully interact with others, it often needs to be able to cooperate, coordinate, and negotiate. This ability of agents to interact with each other separates MAS from other types of simulation models (Wooldridge, 2009). Axtell (2000) reviews the advantages of using MAS over mathematical models. According to him, the advantages of MAS are 1) it is easy to describe agents rationally in MAS, 2) it is easy to make agents heterogeneous and autonomous in MAS, 3) MAS models can be solved and results are obtained by executing it, and 4) it is easy for agents to interact with one another through space, networks, or both. However, he mentions the one significant disadvantage of MAS is that a single run of a model does not necessarily provide sufficient information. The only way to solve this problem is to run the model multiple times.

Humans are self-directed, autonomous, and social (i.e., they are interdependent and interact with other agents), and there is need for models to capture the complexities that arise from the interactions among such autonomous entities in supply chain systems (Macal and North, 2009). For example, the two agents might interact to negotiate price. If agent A is a seller and agent B is a buyer, agent A will tell agent B its price, and if agent B is happy with the price offered it will buy the product; otherwise, the negotiation process would be executed. In negotiation, agent A may come up with a reduced offer for agent B. Agent B, depending upon its level of satisfaction with the offer, may either accept the offer, negotiate further, or walk away from the offer. Such types of complex interactions are easier to represent in MAS than in mathematical models, since the language and concepts used in

MAS is much closer to natural human language and thinking than the equations in mathematical models (Wilensky, 2015). In principle, MAS could be reduced to a set of differential equations; however, the bottom-up approach and the psychology of the modeler differentiate it from other types of models (Fioretti, 2005).

Multi-Agent Simulation Applications

MAS models have been used in computational economics to study the evolution of decentralized market economies (Tesfatsion, 2003). Macal and North (2009) suggest that applications of MAS should not be limited to computational economics, but should be widely applied in various domains, such as stock markets, supply chains, consumer markets, predicting the spread of epidemics, sociology, and biology. A sample of recent applications of MAS modeling is given in Table 1. This list is just a small example that shows the diversity of the application of MAS.

Macal and North (2009) and Siebers et al. (2010) recommend a few features of systems that can be readily modeled using MAS. According to them, MAS should be used when: 1) a problem has a natural representation of agents, 2) agents have relationships with other agents, 3) agents move or change in time or space, 4) agents adapt and engage in strategic behavior, 5) emergent behavior is part of the model or is an expected outcome, 6) agents have to make decisions.

Table 1: Sample of recent multi-agent simulation models and applications (adapted from Macal and North (2009))

Application Area	Model Description
Air Traffic Control	Agent-based model of air traffic control to analyze control policies and performance of an air traffic management facility (Conway 2006)
Anthropology	Agent-based model of prehistoric settlement patterns and political consolidation in the Lake Titicaca basin of Peru and Bolivia (Griffin and Stanish 2007)
Biomedical Research	*The Basic Immune Simulator*, an agent-based model to study the interactions between innate and adaptive immunity (Folcik, An and Orosz 2007)
Chemistry	An agent-based approach to modeling molecular self-assembly (Troisi, Wong and Ratner 2005)
Crime Analysis	Agent-based model that uses a realistic virtual urban environment, populated with virtual burglar agents (Malleson 2009).
Ecology	Agent-based model of predator-prey relationships between transient killer whales and other marine mammals (Mock and Testa 2007).
Energy Analysis	Agent-based model for scenario development of offshore wind energy (Mast et al. 2007).
Epidemic Modeling	*BioWar*, a scalable citywide multi-agent model, that simulates individuals embedded in social, health, and professional networks and tracks the incidence of background and maliciously introduced diseases (Carley et al. 2006).
Market Analysis	Agent-based simulation that models the possibilities for a future market in sub-orbital space tourism (Charania et al. 2006).
Organizational Decision Making	Agent based modeling approach to allow negotiations in order to achieve a global objective, specifically for planning the location of intermodal freight hubs (van Dam et al. 2007).

Applications of MAS in Supply Chain Management

Researchers have recently begun using MAS to model supply chains. Supply chains are complex systems with multiple agents, including suppliers, manufacturers, distributors, and customers, that interact and negotiate with each other over time (Agustina, 2014). This behavior of multiple agents makes a strong case for using MAS to model supply chains. Schieritz et al. (2003) recommend using MAS to model supply chains due to the number of agents involved in interactions using specific decision structures.

Using MAS, one can evaluate various supply chain management policies without affecting real businesses and incurring cost. MAS has been used to test a model of the complex environment of an industrial district (Giardini, 2008). This model enabled the

implementation of an artificial environment where agents choose different suppliers based on performance evaluations. The model consists of two-way flow: forward flow of materials from supplier to buyer, and backward flow of evaluation from buyer to supplier. MAS has also been used to study the performance of supplier selection models and shows that it is better to buy from fewer suppliers (Valluri, 2005). Jiao et al. (2006) used MAS to model a multi-contract negotiation system for a global manufacturing supply chain. They also present a case of mobile phone global manufacturers using MAS for supply chain coordination.

Krejci and Beamon (2015) used MAS to study the impacts of the farmer coordination on the emergence of different types of RFSC structures over time. Their model captures price negotiations between farmer and distributor agents. Bora and Krejci (2015) used MAS to develop a model of farmer selection by a food hub manager in a theoretical RFSC. According to their results, selecting farmers after ranking them as per their performance is a better option than randomly selecting farmers, since the same farmers are retained as suppliers over time. This outcome is consistent with other research, which observes that retaining the same suppliers enables a firm to achieve sustainable growth (Handrinos, 2014).

Research Question

This thesis describes the application of MAS to assess the impact of three different supplier selection policies on the performance of an RFSC that is intermediated by a regional food hub. Both the performance of the individual RFSC members and the overall RFSC performance are of interest. Performance is measured with respect to multiple (and sometimes conflicting) supply chain metrics, including quality, delivery, price, the relationship between the food hub and the supplying farmers, and farm size distribution. The

MAS is also used to determine the extent to which each of the three supplier selection policies would help small- and medium-sized farmers become more economically sustainable.

Methodology

This section describes a multi-agent simulation (MAS) model of a theoretical regional food supply chain (RFSC), which was developed using NetLogo (v. 5.1.0). RFSCs typically consist of several different types of actors (i.e., farmers, distributors, and consumers) that interact periodically in the forward loop of supplying produce and the backward loop of sharing/transferring information. These agents also interact and negotiate with each other to describe and attempt to fulfill their requirements. MAS is well-suited to capturing these heterogeneous actors, their decisions, and their interactions, as well as the outcomes of these decisions and interactions over time. NetLogo is was chosen because of its simple user interface and its ability to model complex systems like supply chains over a period of time (Tisue 2004). Some other advantages of using NetLogo are (NetLogo User Manual 2014):

- It is freely available
- It is fully programmable and the syntax is straightforward
- High speed computation is possible for small numbers of agents (less than 1000)
- It contains a large vocabulary of built-in language primitives

The lengthy process of describing agents, models and sub-models can make them cumbersome (Grimm 2006). Thus a standard protocol is helpful when explaining the model.

In this section, the guidelines given by the Overview, Design concepts and Details (ODD) protocol, as described by Grimm et al. (2006), are followed. The ODD protocol elements are described in the following sections. First, the purpose of the model is described, followed by description of the agents used in the model. Then, an overview of the model is presented. Finally, each sub-model is described in detail.

Purpose

The model described in this thesis was developed to address a problem faced by many regional food hub managers: an inefficient supply chain. Inefficiencies within RFSCs often stem from managers' inability (or unwillingness) to control farmer performance, in terms of cost, quality, and delivery. Food hub managers are keen to understand what policies can be put in place to improve RFSC efficiency and how these policies might affect different measures of performance. The purpose of this model is to test the impact of different supplier selection policies on the objectives of a food hub and the farmers that supply it with food. Food hub objectives include providing consumers with high-quality food, ensuring the timely deliveries by the farmers, and supporting the social welfare of smaller-scale farmers. Farmer objectives include improving profits and maintaining autonomy.

As previously discussed, supplier performance is typically measured in terms of quality, delivery, price, and the relationship between the supplier and the buyer. Depending upon the industry in which the supply chain is embedded, the relative importance of these parameters may differ. For example, in the automobile industry, quality, delivery, and relationships are of utmost importance when selecting suppliers, while cost is relatively unimportant (Choi 1996). Therefore, this model is tailored specifically to represent an RFSC,
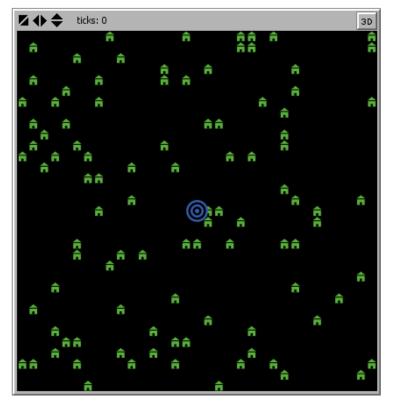
such that the importance of each supplier performance metric reflects the preferences and expectations of food hub managers. In order to assess these preferences, the managers of two Iowa food hubs (i.e., the Iowa Food Co-op in Des Moines and the Iowa Valley Food Co-op in Cedar Rapids) were interviewed, and their feedback was incorporated into the model. Thus the model can be used to assess the impact of explicitly considering supplier performance when selecting suppliers in an RFSC. The ability to test this type of scenario is particularly useful for food hub managers, who typically do not employ a systematic method of selecting suppliers and may benefit from data-driven supplier selection policies.

Entities and Variables

A typical RFSC has three echelons – farmers, a distributor, and consumers. The model described here is focused on the interactions between the farmers and the regional distributor (i.e., the food hub). Therefore, the customers are not explicitly represented as agents. Instead, the demand generated by the food hub represents the demand of the customers. In this section, the two types of agents that exist in this model are described: 1) farmers and 2) a regional food hub manager. The farmer agents produce food and seek market channels for its distribution, and the food hub manager purchases food from the farmers to satisfy its demand. As shown in Figure 4, the food hub (represented by a bullseye) is located at the center of the region, and the farmers (represented by houses) are distributed randomly throughout the region. The area of this region is 460 x 460 sq. miles.

Figure 4 : Agent representation

Farmer Agents

The model consists of 100 farmers distributed randomly throughout the region. The

geographic location of each farmer is assumed to be fixed for all experiments. The distance

between a farmer and the food hub is calculated as a Euclidean distance (i.e., roads are not

taken into account). Each farmer is assigned a specific farm size category (small, medium,

large, or very large), based on its revenues (see Table 2). In this model, the farm sizes are

distributed as per the U.S. Census of Agriculture, such that 79% of the farms are small, 15%

are medium, 3% are large, and 3% are very large (USDA 2012). The farmers are randomly

assigned a revenue value as per their farm sizes; for example, a farmer with a small farm will

be assigned a revenue value that is between $5,000 and $49,000. In the model, carrots are

assumed to be the single crop produced and sold. The average price at which the farmers sell

carrots is 0.59/lb. (USDA 2012). Using this price and the revenue value of the farmer, the total production capacity of the farmer is determined.

Table 2: Farmer Classification

Revenues (in $)	Farmer size	% of farms	% sales	w
5000-49999	Small	79	10	2
50000-249999	Medium	15	23	2
250000-500000	Large	3	11	4
500000+	Very large	3	56	4
	Total	**100**	**100**	

The farmers are autonomous and work independently to produce food in each time-step, where one time-step represents a single transaction cycle, which is equivalent to one week. Farmers do not communicate with one another, nor are they capable of observing other farmers' behaviors and outcomes. Farmers' profits are earned via sales to the food hub and/or other customers (e.g., farmers' markets, mainstream distributors). Since the focus of our model is to study the relationships between the farmers and the food hub, the other customers are exogenous to the model (i.e., they are not represented as agents). It is assumed that the farmers prefer to sell to the food hub because it offers a better prices and more efficient transactions than other customers. However, the literature suggests that farmers are generally risk-averse (Hildreth 1982). That is, they do not want to put all their eggs in one basket. Although the food hub is the preferred market channel, a farmer typically will not sell his entire yield to the food hub, in order to maintain his autonomy and not be wholly dependent on a single customer for his business.

The objective of each farmer is to be profitable as well as autonomous (i.e., not dependent on a single customer). In order to understand the effects of these conflicting

objectives on the farmer agents' decisions and behaviors, a weighted aggregated utility function ($U(x)$) is assigned to every farmer. The weighted aggregated utility function is an exponential function that incorporates the farmer's preference for increasing profits while at the same time mitigating risk (Hildreth 1982). $U(x)$ is the weighted sum of two components: the utility the farmer gains by making sales to the food hub ($U(x_1)$) and the utility he gains from selling to other customers ($U(x_2)$). $U(x_1)$ represents the utility that a farmer gains when x_1 percent of his total sales are through the food hub, as shown in Equation (1). Similarly, $U(x_2)$ is the utility that a farmer gains when x_2 percent of his total sales are to other customers, as shown in Equation (2). x_1 and x_2 always sum to 100%, based on the assumption that all of a farmer's yield is either sold to the food hub or to other customers. In Equations 1 and 2, $1/R$ represents the farmer's degree of risk preference and is positive for all farmers (based on the assumption that they are risk-averse), where R is the minimum revenue generated by the farmer by selling his entire production at the lowest possible price (i.e., $0.59/lb).

Equation (3) is the weighted aggregated utility function $U(x)$ of the farmer, where w is the weight given to the utility of selling to customers other than the food hub, representing the relative importance of these customers to the farmer. The weights were derived by pairwise comparison as described by (Onut 2009), in which $w = 2$ represents weak importance and $w = 4$ represents strong importance. In this model, it is assumed that small and medium-sized farmers consider customers other than food hub to be relatively less important ($w = 2$), while large and very large farmers consider customers other than food hub to be very important ($w = 4$). For small and medium farmers, the food hub connects them to a market with better than average prices, which is otherwise difficult for them to reach; thus the food hub is more important than other customers. For large and very large farmers, the

conventional customers or the customers other than food hub provide a consistent source of demand and can purchase their large volumes of produce. This is the most important reason for large and very large farmers to consider customers other than food hub as highly important.

$$U(x_1) = 1 - e^{\left(\frac{-x_1}{R}\right)} \tag{1}$$

$$U(x_2) = 1 - e^{\left(\frac{-x_2}{R}\right)} \tag{2}$$

$$U(x) = \frac{U(x_1) + wU(x_2)}{1 + w} \tag{3}$$

Food Hub Manager Agent

In this model there is one food hub located at the center of the region. The main objective of the food hub's manager is to ensure that regionally-produced food of the highest quality is supplied to the food hub's customers. Therefore, quality is a very important component of measuring supplier performance. However, the food hub has several other objectives, and these are also reflected via supplier performance metrics. For instance, since the food hub has limited operating manpower, it is important to the manager that the farmers schedule their delivery times and adhere to this schedule (Huber 2015). Additionally, as part of its social mission, the food hub is strongly motivated to support small- and medium-sized farmers (Muldoon 2013). In fact, one of the defining characteristics of a regional food hub is its commitment to buy from small- and medium-sized farmers whenever possible (Barham 2012). Thus the overall value that a given farmer provides the food hub (i.e., the farmer's "performance") is composed of multiple elements with different degrees of importance to the

food hub. The performance metric is described in detail in the "Performance" submodel

section below.

Model Overview

In each time-step (i.e., distribution cycle), the food hub manager agent generates demand on

behalf of its customers. In this model, the demand is uniformly distributed between 24,000

lbs and 25,000 lbs. Once the demand is generated, the food hub manager will select the

farmers as per his designated supplier selection policy. The supplier selection policies are

explained in details in the "Supplier Selection" submodel description below. The farmer will

continue selecting farmers until the demand is satisfied. Once the demand is satisfied, the

food hub evaluates each selected farmer as per the performance metric.

Figure 5 provides an overview of the model. The food hub manager acts as the driver of

the model. After the farmer and the food hub manager agents are created, the food hub's

demand is generated. The food hub manager then starts the process of selecting the farmers

as per one of three possible supplier selection policies:

- Policy 1: Random selection of farmers
- Policy 2: Selection of farmers based on their performance ranking
- Policy 3: Contracting the top performing farmers

Once a farmer is selected, the food hub manager and the farmer interact with each other to

determine whether negotiation is needed. If there is a need for negotiation, the negotiations

are held. The manner in which negotiations are conducted is described in detail in the

"Farmer-Food Hub Negotiation" submodel section below. Once the negotiations are

complete, the farmer is assigned new attribute values (cost, defects, fh_ratio and delivery) as

per the negotiated terms. The food hub manager then purchases food from the farmer. If the negotiation is unsuccessful, or if there is no need for negotiation, the food hub manager purchases the food from the farmer as per the existing terms.

Once the transaction is complete, the food hub manager once again checks the demand. If the demand is not satisfied, the food hub manager now selects a new farmer and the process mentioned above is followed. If the demand is satisfied, the process of selecting farmers is terminated. The food hub then evaluates the performance of the selected farmers. This completes one time-step. For the next time-step, a new demand is generated and the cycle is repeated.
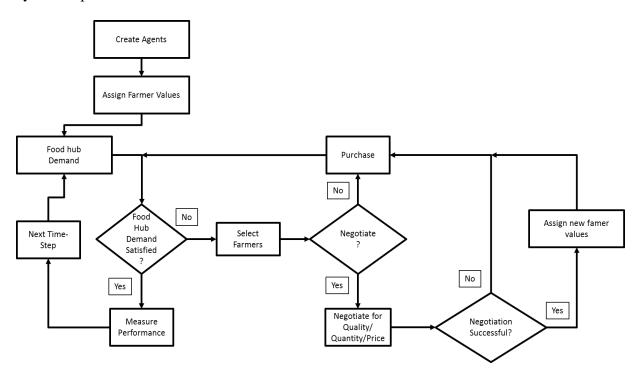

Figure 5 : Model Overview

Table 2 and Table 3 describe all the necessary information regarding all the important parameters and variables used in the model.

Table 3: Parameter Values

#	Parameter	Description	Possible Values	Source of values
1	farmer_num	Unique identification number of farmer	1-100	-
2	Xc	x-cordinate of the farmer	160 miles	Assumption
3	Yc	y-cordinate of the farmer	160 miles	Assumption
4	farm_land	Farm land of farmer in acres	1-2000 acres	Assumption
5	farm_size	Size of the farmer classified as small, medium, large or very large as per the farm_land	small, medium, large and very large	USDA
6	distance_origin	Distance of the farmer w.r.t food hub	10 - 225 miles	Euclidean geometry
7	coqc	Cost of quality control	$0.05/lb	Assumption
8	trans	Cost of transportation	$0.25/mile	Experimental
9	sp_reg	Selling price to the other customers	$0.59/lb	USDA
10	farm_revenues	Revenue of farmer	-	USDA
11	farm_yield	Maximum yield of the farmer		USDA
12	min_farmer_profit	Calculates the minimum profit a farmer would earn under any circumstance	-	Assumption
13	weight	Weightage given to the utility of non-food hub sales and is size dependent	2 or 4	Önüt (2009)
14	utility_value	Minimum expected utility value of the farmers and is size dependent	0.325, 0.450 & 0.505	Wallace Center Utility function

Submodels

This section describes the five submodels that comprise the main model: initialization and

setup, farmer utility, performance, farmer-food hub negotiations, and supplier selection.

Table 4: Variable Values

#	Variables	Description	Possible Values	Generation of values
1	sp_pre	Selling price premium i.e. price at which farmers sale to the food hub	$0.75 - $1.25/lb	Uniform distribution
2	cp_prod	Production cost incurred to the farmer as per USDA	$0.225 - $0.275/lb	Uniform distribution
3	yield	% of farm_yield uniformly distributed from 80% to 100%	80-100%	Uniform distribution
4	farmer_production	Amount of crop a farmer can produce at a given time (units in lb)	-	Model
5	farmer_utility	Calculates the utility value of every farmer	0-1	Utility function
6	fh_ratio	% of total farmer_production the farmer will sell to food hub	0-80	Utility function
7	food_hub_qty	Amount of quantity farmer will sell to food hub	-	Utility function
8	farmer_selection	Checks whether farmer is already selected	-	Supplier selection policy
9	farmer_fh_rev	Revenues earned by farmer by selling to food hub	-	Utility function
10	farmer_trans_cost	Transport cost incurred by farmer to deliver to food hub	-	Model
11	farmer_fh_cost	Production cost of quantity delivered to food hub	-	Model
12	farmer_coqc	Cost of quality incurred by farmer to supply to food hub	-	Model
13	defects_pr	Probability of farmer supplying defects	0-20%	Uniform distribution
14	farmer_delivery_pr	Probability of farmer delivering	50-100%	Uniform distribution
15	farmer_fh_profit	Profit of the farmer through food hub	-	Model
16	farmer_other_qty	Quantity sold to others other than food hub	-	Utility function
17	farmer_other_rev	Revenues collected through sales to others	-	Utility function
18	farmer_other_profit	Profit through others	-	Model
19	farmer_total_profit	Total profit of farmer	-	Model
20	fh_demand_crop1	Demand for crop1 in lbs	24000-25000 lbs	Uniform distribution
21	delivery_pr	% of farmers who would delivery	25% - 45%	Uniform distribution
22	fh_profit	Profit of food hub	-	Model
23	total_negotitation	Total number of negotiations held between the food hub & the farmers	-	Model

Initialization and Setup

At time-step 0, the model is set up. The farmer and the food hub manager agents are created and assigned their respective locations, and initial farmer parameter values are assigned. To represent the uncertainty that characterizes crop production, yield values for each farmer (farmer_production) are set between 80-100% (uniformly distributed) of the maximum possible production. The fh_ratio, which is defined as the percentage of yield that the farmer would sell to the food hub, is 20%, 5%, 1% and 1% for small, medium, large and very large farmers, respectively. . For example, if fh_ratio is 20% and the yield is 100 lbs, then the farmer would sell 20 lbs to the food hub. The farmer's production cost (cp_prod) is uniformly distributed in the range of \$0.225 - \$0.275/lb (USDA 2012). The price at which a farmer sells his product to the food hub (sp_pre) is uniformly distributed in the range of \$0.75 - \$1.25/lb. sp_pre is higher than sp_reg (i.e., the price at which the farmer sells his products to non-food hub customers), which is set to \$0.59/lb (USDA 2012)) since it includes transportation cost. It is also observed that the farmers sell their products to the food hub at a premium price because of better and diverse quality of it produce. The values (i.e., cp_prod and sp_pre) vary within their respective range in each time-step. The cost of transportation (e.g., for fuel) is as assumed to be \$0.25 / mile. The transportation cost for each farmer is then calculated by multiplying the Euclidean distance between the farmer and food hub by the cost. For non-food hub customers, it is assumed that the buyer will pick up the products from the farmer's location.

Based on a discussion with the manager of the Iowa Food Co-op, the percentage of farmers who schedule their deliveries (delivery_pr) is 25-45% (Huber 2015). Scheduling the delivery is essential – it helps the food hub manager to effectively schedule his workforce,

thereby improving the efficiency of the supply chain. To represent this in the model, for the first five time-steps, 25-45% of farmers are randomly selected as the farmers who schedule their deliveries. Farmers who scheduled their delivery at least four times out of five in first five time-steps are considered to be highly motivated farmers who can be counted on to schedule their deliveries in the future. It is assumed that these highly motivated farmers are guaranteed to schedule their deliveries in every time-step for the remainder of the simulation. Other farmers are assumed to have 75% chance of scheduling their delivery in any given future time-step (farmer_delivery_pr). The Iowa Food Co-op manager also mentioned that the percentage of farmers supplying high-quality products is 90% in each time-step (Huber 2015). To represent this in the model, 10% of farmers are randomly selected in each of the first five time-steps who will supply poor-quality products.

Once these values are initialized, farmer agents are randomly selected by the food hub manager. Random selection occurs for first five time-steps to initialize the agents in the model. Five time-steps is sufficient enough to generate data required to categorize farmers according to their quality and delivery patterns. The conditions are set such that demand is greater than supply for the first five time-steps, so that every farmer is selected. At time-step 5, farmers are classified as being best, average, or poor, with respect to quality. Farmers with high prices (prices above 7.5% of expected value of $1.00/lb) and no defects in the first five time-steps are considered to be best-quality farmers. Farmers with low prices (prices below 7.5% of expected value of $1.00/lb) are considered to be poor quality farmers because it is assumed that the probability of these farmers supplying poor quality produce is high, assuming positive correlation between a product's price and its quality (Ordonez 1998). All other farmers are considered to be average, in terms of quality. After the first five time-steps
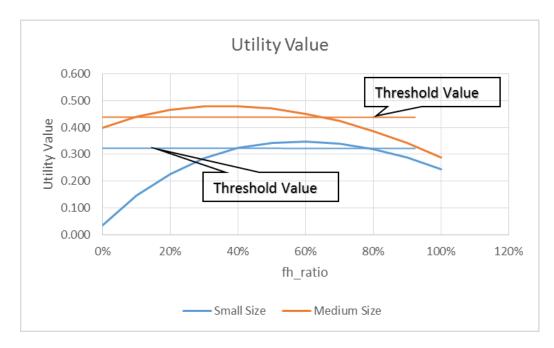
farmers with best quality have a 5% chance of supplying defective products in any given time-step, while farmers with average and poor quality have 10% and 20% chance of supplying defects, respectively. Farmers supplying the best quality produce are assumed to sell their food at a high price; thus the farmers with high quality would sell their products in the range of $1.00 - $1.25/lb.
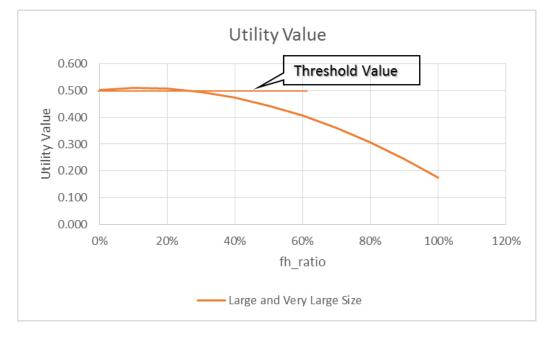
Farmer Utility

After initialization, farmer utility values are calculated as described in Equations (1), (2) and (3). Figure 3 represents the utility values $U(x)$ observed with respect to fh_ratio of 0-100% for small, medium, large, and very large farmers. Based on an unpublished survey generated by the Wallace Center at Winrock International, which stated that a small farmer would like to sell around 63% of its yield to the food hub, while a medium-sized farmer would like to sell around 30% of its yield to the food hub, and the large and very large farmers would like to sell in the range of 0 – 13%, the threshold values for small, medium, and large and very large farmers are set to 0.325, 0.450 and 0.505 respectively (see Figure 6). In Figure 3(a) the utility function plot is concave due to the importance of customers other than the food hub, in order to maintain sufficient autonomy. The small and medium farmers do not want to be completely dependent on the food hub for their sales, i, thus the utility decreases after fh_ratio = 60% for small farmers and 40% for medium farmers. Since the profit of small farmers is less compare to medium farmer (for example profit of small farmer is $150 while that of medium farmer is $600 if both the farmers have fh_ratio = 30%), the small farmer needs to sell higher volumes (fh_ratio), to achieve maximum utility to the food hub. For large farmers and small farmers, the utility curve is similar (see Figure 3(b)).

(a)

(b)

Figure 6: Utility functions for a) small and medium farmers and b) large and very large farmers

Performance

The food hub manager evaluates the performance of each selected farmer at the end of a transaction cycle (time-step). The performance of farmers is evaluated on five key parameters of the RFSC: 1) food quality (Q), 2) delivery scheduling by the farmers (D), 3) food cost (C), 4) farm size (S), and 5) previous performance (A). Table 5 describes the weights carried by each parameter. The weights were determined after speaking with the food hub managers at the Iowa Food Co-op in Des Moines and the Iowa Valley Food Co-op in Cedar Rapids. Total farmer performance (P) is the weighted sum of these five parameters (see Equation (4)).

Table 5: Performance metrics

	Farmer Performance Parameter	Weight
1	Quality (Q)	35%
2	Delivery (D)	30%
3	Cost (C)	15%
4	Farm Size (S)	10%
5	Previous Performance (A)	10%
	Total	**100%**

$$P = 0.35Q + 0.30D + 0.15C + 0.10S + 0.10A \qquad (4)$$

Quality in fresh foods is very difficult to define in terms of specifications or standards because of their perishable nature, varied consumer tastes, and different consumer preferences for nutritional values. However, regional food hubs tend to define quality as products having proper packaging and labeling, as well as being fresh and clean (Muldoon 2013). Because transparency and traceability is so critical in the RFSC (i.e., the customer wants to know which farmer produced the food they purchased), having clean and clear

labels is very important. Good packaging and clean products show that the farmers are serious about quality. As shown in Table 3, quality (Q) is the most important of the five farmer performance components, with a relative weight of 35%. The value of Q = 0 if the farmer supplies defective products and Q = 1 if the farmer supplies non-defective products.

However, delivery (D) is also an important parameter to evaluate a supply chain. Delivery scheduling by farmers enables food hub managers to effectively plan their resources. Interviews with food hub managers indicate that after quality, delivery is the second most important performance component. As shown in Table 5, delivery therefore has a weightage of 30%. If the farmer schedules a delivery with the food hub, then the value of D = 1; otherwise, D = 0 for that farmer.

Product cost (C) is relatively unimportant as far as the food hub managers are concerned, because most food hubs are driven by the motivation to support small- and medium-sized farmers. However, they would like to ensure that the farmers sell their products at reasonable prices, which can attract a large customer base. In this model, if the unit price of the farmer's product is more than 10% above the expected selling price ($1.00/lb), then the value of C = 0; otherwise C = 1.

As stated earlier, the food hub managers are keen to support small- and medium-sized farmers, hence a 10% weightage is given to farmer size (S) in the performance equation. In this model, if the farmer is small or medium, then S = 1; if the farmer is large or very large, then S = 0. By providing this additional weightage, small and medium farmers get a head start in the process of selection when the selection policy is based on performance. Thus the performance metric is modified as per the objectives of the food hub to support the social welfare of small and medium farmers.

Another important supply chain parameter captures the buyer's relationship with the suppliers. The relationship between the farmers and the food hub is defined in terms of the length of relationship, reliability, consistency and the quality of the products supplied by the farmer. The previous performance helps capture the consistency of farmer's performance over time. The previous performance metric (A) is given a 10% weightage in the performance equation. In this model, the values of A range from 0 to 1. For example, if the value of A > 0, then the farmer was selected in the previous cycle, where the value of A depends upon the performance of the farmer in previous cycle. If the farmer was not selected in previous cycle, i.e. there is no record for the farmers performance due to lack of consistency, the value of A in such case is 0.

Based on the maximum possible values of Q, D, C, S, and A, the maximum value of P = 1. Since the quality and delivery of farmers may improve over time due to continuous negotiations between the farmers and the food hub, the value of P is generally in the range of 0.7 – 1.0. The median value of P = 0.9, while the mean value of P = 0.8.

Farmer-Food Hub Negotiations

Negotiation is the method by which the food hub manager and the farmers interact with each other to alter one or more of the initialized values regarding quality, price, and quantity of the food that is traded. In this model, the success rate for negotiation is randomly set to 75% (i.e., 75% of negotiations will be successful). However, a sensitivity analysis was performed to analyze the effect that the negotiation success rate has on different supplier selection policies. Negotiation can be initiated either by the food hub manager or the farmer. A farmer can initiate negotiation either to increase prices or to change the quantity of food sold to the food hub (i.e., fh_ratio). The food hub manager can initiate negotiations either to decrease prices

or to improve the quality of the farmer's product (in the case of poor or average quality farmers).

Negotiations for quantity

Only farmers can initiate this type of negotiation. The farmer will initiate negotiations to either increase or decrease the quantity of food that he supplies to the food hub (fh_ratio) if the farmer utility is less than the threshold utility value (i.e., farmer_utility < utility_value). The increment/decrement (delta) in fh_ratio is by 5%, 2%, 0.1% and 0.1% for small, medium, large and very large farmers, respectively. The delta is negative, if the fh_ratio is on the higher side. For example in Figure 3(a), for a small farmer, if the farmer_utility is below the threshold value (0.325) and fh_ratio is 95% (i.e., the farmer is supplying more volume than he would prefer), then the delta will be negative. If the farmer_utilty is below the threshold and fh_ratio is 20% (i.e., the farmer is supplying less volume than he would prefer), then delta is positive. Every time the farmer initiates this negotiation, the fh_ratio is altered by delta.

Negotiations for cost

Negotiation for cost can be initiated either by the farmer or the food hub (see Figure 7). The food hub will initiate the negotiations to modify cost if the selling price is more than 10% of the expected price ($1.00/lb). If the negotiations are successful then the new price (sp_pre) will be in the range of $1.00 - $1.15/lb. If negotiations are not successful, the farmer will sell the food hub at current price. The farmer will initiate the negotiations to alter the cost if the selling price (sp_pre) is less than 10% of the expected price ($1.00/lb). If the negotiations are successful then the new price (sp_pre) will be in the range of $0.90 - $1.05/lb. If negotiations are not successful, the farmer will sell the food hub at current price.
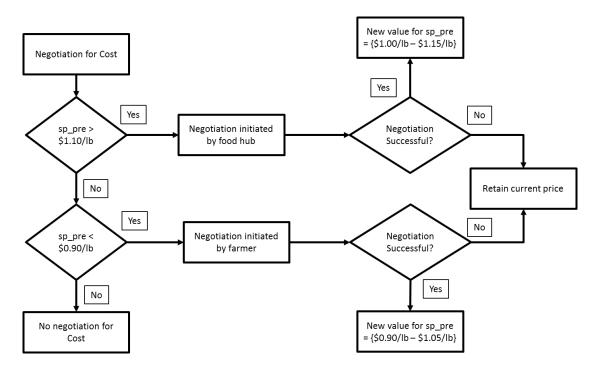
Figure 7: Negotiation for cost

Negotiations for quality

Only the food hub manager can initiate this type of negotiation. The food hub manager will initiate negotiation to improve the quality of a farmer's products only if the farmer supplies defective product. If the farmer is a poor quality farmer, then the food hub will ask him to improve from poor to average. If the farmer is an average quality farmer, then the food hub will ask him to improve from average to best. For example, if the farmer is in previous time-step supplied defective products, then the food hub manager will initiate negotiations with the farmer to improve quality. If the negotiations are successful, then the farmer upgrades his quality to the next level, i.e. from poor quality to average quality or from average quality to best quality. There is no scope for improvement if the farmer is already a best quality farmer. However, in this case a negotiation still occurs, since it is assumed that the food hub manager will give some feedback to the farmer regarding the defects observed.

Negotiation is one of the most important aspects in any transaction. It is sometimes time consuming and also requires additional manpower. As can be seen from the research by (Bora and Krejci 2015), negotiation also act a tradeoff between policies and can help improve the performance of the supply chain.

Supplier Selection

The most important contribution of this model is to understand how different supplier selection policies affect the metrics of an RFSC. As per the objectives of the food hub, the most important performance metrics include farmer performance, the percentage of farmer yield supplied to the food hub, farm size distribution of selected farmers, number of farmers selected, consistency of farmers supplying to the food, and the total number of negotiations that occur between the food hub manager and the farmers. The three possible supplier selection policies available to the food hub manager in this model are:

- Policy 1: Random selection of farmers
- Policy 2: Selection of farmers based on their performance ranking
- Policy 3: Contracting the top performing farmers

These policies are varied experimentally to assess their effectiveness with respect to the multiple RFSC metrics of interest. In any given experimental scenario, it is assumed that the manager will only follow one of these policies (i.e., he cannot switch back and forth between policies).

Policy 1

Policy 1 is the random selection of farmers. This is a status quo policy currently used by the Iowa food hub managers. In this policy the food hub randomly selects the farmers to satisfy its demand in each time-step.

Policy 2

Policy 2 involves selecting the farmers based on their performance ranking. With this policy, after evaluating the farmers at the end of a transaction cycle (say time-step *t*), the food hub manager ranks them with respect to their performance. At time-step *t+1* the food hub selects farmers based on the ranking given at end of time-step *t*. The farmers are selected by rank order until the demand is satisfied. In case of a tie, the tie is broken by selecting the farmer randomly.

Policy 3

Contracts are essential in order to ensure regular and consistent supply, build relationships, reduce the need for negotiations, and promote best practices. Policy 3 involves selecting the farmers based on their performance ranking and then contracting with them for a specific period of time. With this policy, farmers that have a performance value (P) that is above a threshold (experimental value = 97%) during the contract evaluation cycle (i.e., 20 time-steps) are awarded a contract for 20 time-steps. It is assumed that the farmers will definitely accept the offers given by the food hub manager. If the demand is not satisfied by the contracted farmers, then non-contracted farmers are selected based on their performance ranking (similar to Policy 2). These non-contracted farmers then satisfy the remaining demand. After 20 time-steps, again the farmers with performance above the threshold value are rewarded with a contract for the next 20 time-steps.

In Policy 3, contract terms with respect to quality, cost and quantity are fixed (i.e. the contracted farmers are assumed to uphold these terms for all 20 time-steps). The farmer agrees to consistently provide good quality products. Farmers with farm size small, medium, large and very large will maintain an fh_ratio of 0.65, 0.45, 0.10 and 0.10 respectively. The

farmers would sell the produce to the food hub in the price range of $1.00 - $1.15/lb. There are no negotiations held with the contracted farmers until the contract expires.

The possibility of the food hub manager or the farmers reneging on a contract is not considered, although this is a serious risk in reality. For example, the food hub manager will continue to buy from a contracted farmer, even if he supplies defective products, until the contract term is over. Additionally, it is assumed that a contracted farmer must sell the agreed-upon volume to the food hub in each time-step until the contract term is over, even if there is a possibility that the farmer might get a better price from other customers.

Simulation Results and Analysis

The model was used to run experiments to test the impact of three different supplier selection policies on a variety of supply chain metrics. The three policies for selecting suppliers are as follows:

- Policy 1: Random selection of farmers
- Policy 2: Selection of farmers based on their performance ranking
- Policy 3: Contracting the top performing farmers

The output metrics that were captured for each time-step include: the number of farmers selected, the distribution of selected farmer sizes, average selected farmer performance, the number of farmers negotiating, the percentage of farmers scheduling delivery, the profit made by the food hub, and the volume supplied by the farmers to the food hub by farmer size. These metrics were selected because they directly relate to the food hub's economic and social objectives. For each of these policies, 30 replications of 150 time-steps each were run. The initial 75 time steps were considered as a warm-up period, to allow the system to

stabilize. Therefore, the final 75 of 150 time-steps were considered for evaluating and comparing the three policies. One time-step is equivalent to one transaction cycle. (i.e., one week). Thus 75 time-steps is equivalent to 75 weeks. 75 weeks (1.5 years) is a sufficient amount of time to understand the impact of the policies.

Table 6 gives a summary of key performance measures evaluated for the three policies and their statistical comparison. It is clear that the three policies are quite different from each other with respect to these performance measures. A t-test was performed on the mean values for each output metric in the final time-step to determine whether the observed differences between the three policies were statistically significant ($\alpha = 0.05$).

Table 6: Statistical Data of three Policies

	Policy 1		Policy 2		Policy 3	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
Peformance	0.84	0.01	0.98	0.00	0.98	0.00
Negotiation	15.84	0.89	11.43	2.40	6.95	1.36
% of Farmers scheduling delivery	67.36	2.32	99.60	0.43	93.19	1.57
% of Quality Issues	9.33	0.44	4.96	0.31	5.05	0.46
Food hub profit	2922.97	275.02	4125.81	146.55	4166.11	139.88
fh_ratio* Small	0.34	0.01	0.36	0.02	0.64	0.01
fh_ratio* Medium	0.38	0.01	0.32	0.02	0.45	0.00
fh_ratio* Large	0.08	0.00	0.01	0.01	0.02	0.01
fh_ratio* Very Large	0.08	0.00	0.02	0.03	0.02	0.02
Total Selected Farmers	52.97	1.15	58.77	7.99	35.96	3.31
Small farmers	41.58	1.09	43.58	8.54	29.90	3.28
Medium farmers	8.13	0.16	11.75	1.22	5.81	0.77
Large Farmers	1.64	0.11	0.12	0.18	0.20	0.14
Very large Farmers	1.62	0.08	0.28	0.36	0.36	0.32

Table 7: Statistical Comparison of Policies

	Policy 1 vs Policy 2		Policy 1 vs Policy 3		Policy 2 vs Policy 3	
	p-value	Conclusion	p-value	Conclusion	p-value	Conclusion
Peformance	0.00	Policy 2 is better	0.00	Policy 3 is better	0.09	**Similar**
Negotiation	0.00	Policy 2 is better	0.00	Policy 3 is better	0.00	Policy 3 is better
% of Farmers scheduling delivery	0.00	Policy 2 is better	0.00	Policy 3 is better	0.00	*Policy 2 is better*
% of Quality Issues	0.00	Policy 2 is better	0.00	Policy 3 is better	0.19	**Similar**
Food hub profit	0.00	Policy 2 is better	0.00	Policy 3 is better	0.15	**Similar**
fh_ratio* Small	0.00	Policy 2 is better	0.00	Policy 3 is better	0.00	Policy 3 is better
fh_ratio* Medium	0.00	*Policy 1 is better*	0.00	Policy 3 is better	0.00	Policy 3 is better
fh_ratio* Large	0.00	Policy 2 is better	0.00	Policy 3 is better	0.03	Policy 3 is better
fh_ratio* Very Large	0.00	Policy 2 is better	0.00	Policy 3 is better	0.44	**Similar**
Total Selected Farmers	0.22	**Similar**	0.00	*Policy 1 is better*	0.00	*Policy 2 is better*
Small farmers	0.29	**Similar**	0.00	*Policy 1 is better*	0.00	*Policy 2 is better*
Medium farmers	0.00	Policy 2 is better	0.00	*Policy 1 is better*	0.00	*Policy 2 is better*
Large Farmers	0.00	Policy 2 is better	0.00	Policy 3 is better	0.08	**Similar**
Very large Farmers	0.00	Policy 2 is better	0.00	Policy 3 is better	0.38	**Similar**

Model Validation – Policy 1 as status-quo

According to a survey prepared by Wallace Center at Winrock International, currently small farmers supply 39% of their total yield to a food hub. As per Policy 1 in the simulation, the small farmers on average supply 34% of their volume to the food hub (fh_ratio = 0.34).

These values are nearly the same. Also, the data published by Fischer (2013) states that around 70% of food hubs have fewer than 70 producers, and 54% of food hubs have fewer than 40 producers. On average, the number of producers doing business with a food hub in any given transaction cycle is 80. As per Policy 1, the mean number of farmers supplying to the food hub in the final time-step of the simulation is 52.90, which falls into the real-world range. Generally food hubs work with a large range of farmers (Fischer, 2013). This is because the food hubs want to have diverse types of products. According to Policy 1, 94% of selected producers are either small or medium-size. As per the USDA (2012), 94% of the farmers who sell to the retail store and food hubs are either small or medium-sized. Therefore, Policy 1 is consistent with the current situation in the real world.

Policy Comparison

From the Table 7, it is clear that Policy 2 and Policy 3 are much better than Policy 1 with respect to all of the supply chain metrics These results suggest that food hub managers should seriously consider adopting one of these two policies to guide their farmer selection process.

Performance and Quality

The average farmer performance under Policy 1 is significantly lower than Policies 2 and 3, as can been seen from Figure 8. This is because the producers are randomly selected to satisfy the consumer demand. There are no controls in place to ensure quality of the products. In Policies 2 and 3, producers are selected on the basis of their performance, and as a result, supply chain performance improves over time. This can also be observed from the fact that the Policy 1 has significantly more total quality issues (4.93) on average than policies 2

(2.78) and 3 (1.85). According to Huber (2015), in any given transaction cycle, approximately 7-10% of farmers will supply defective items. As per Policy 1, it is observed that about 9.5% of farmers on average are supplying defective products. Policies 2 and 3 result in 5.2% and 4.9% of farmers supplying non-conforming products, respectively, as can be seen in Figure 9. The variability observed in Figure 9 for quality defects is due to stochastic nature farmer's quality. Huber (2015) mentions that it is very difficult to predict which farmer, how many farmers and when would these farmers supply defective produce. The graph in Figure 9, reciprocates this stochastic behavior in the model.

Delivery Scheduling

According to Policy 1, the average percentage of farmers scheduling their delivery is 67%. This is comparatively higher than the initial input values for the model, which range from 25-45%. This is because over time the food hub manager interacts and negotiates with farmers to start scheduling. However, they are unable to achieve 100% farmer scheduling. It is important to note here that real-life food hub managers find it very difficult to ask farmers to schedule their deliveries, even though delivery scheduling could greatly benefit food hub operations (Huber, 2015). For Policies 2 and 3, the percentage of farmers scheduling deliveries is significantly higher, as can be seen in Figure 10. In Policy 2, this number is almost 100%. The incentive of getting selected if the farmer starts scheduling can be clearly observed in this policy. In Policy 3 the percentage of farmers scheduling is 93%. This value is significantly lower than that observed in Policy 2, although it is significantly greater than Policy 1. It seems that once the farmer is contracted for a term, there may be a possibility that he would occasionally not adhere to the contract terms, and the food hub has very little

recourse. This is one of the trade-offs between Policy 2 and Policy 3, which the food hub manager should keep in his mind while making a decision to select a particular policy.
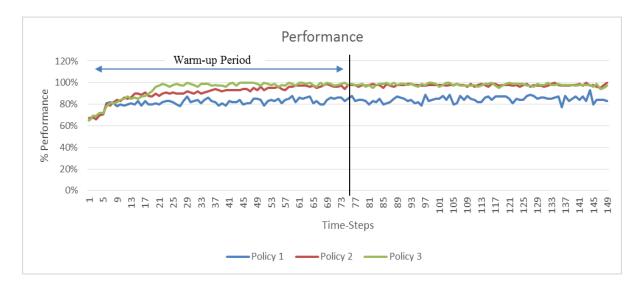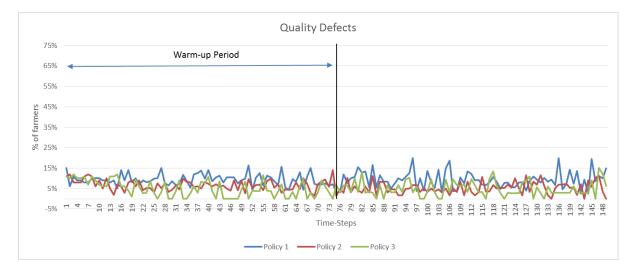

Figure 8: Performance Comparison
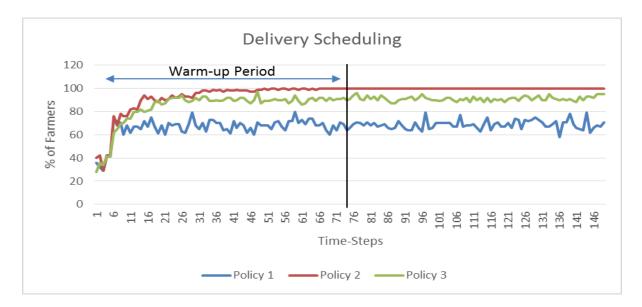

Figure 9: Quality Issues

Figure 10: Delivery Scheduling

Negotiations

Figure 11 shows the percentage of farmers the food hub conducts negotiations with in each time-step. It can be observed that Policies 2 and 3 require comparatively fewer negotiations than policy 1. However, in Policy 3 there are spikes observed, with negotiations ranging to 110% of farmers. For example, at time-step 60, the percentage of farmers negotiating is 104% (i.e., 29 farmers held negotiations with the food hub but only 28 were successful and selected). The contract term of farmers is 20 time-steps. Thus a spike in negotiations is observed for Policy 3 after each 20-time-step contract period. Except for the periodic renewal of contracts the percentage of farmers negotiating is within the range of 0 – 27% in Policy 3. For Policy 2, the percentage of farmers negotiating ranges from 6 – 35%, while for policy 1 this range is from 14 – 45%.
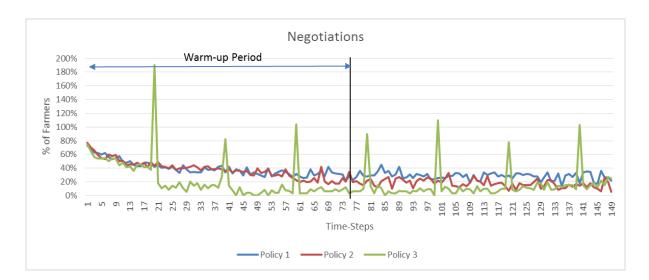
Figure 11: Negotiations

Farmer Size Distribution

One of the major objectives of the food hub is to support and promote small and mid-sized farmers. It is of special interest to the food hub managers to understand how the policies will help them achieve their objective of supporting small and medium farmers. Figure 12 shows that for Policy 1, the food hub on an average selects 78% small farmers, 15% mid-sized farmers and 3% large and very large farmers. This trend is similar to observed by the USDA (2012). The food hub managers want to develop policies which will support their objective of selecting as many as small and medium-sized farmers possible. Policy 2 and Policy 3 are a step in that direction. In Policy 2, the share of large and very large farmers is transferred to medium-size farmers. In Policy 3, the share of large and very large farmers is transferred to small farmers. As can be seen from Table 6, there is no significant difference (i.e. p-value $>$ 0.05) between total number of farmers selected by the Policy 1 or Policy 2. However there is a significant difference between total number of farmers selected by Policy 3 and Policies 1 and 2. Thus we can conclude that the contractual policy plays an important role in determining the total number of participating farmers.

Figure 12: Farmer Distribution

Farmer Sales

One of the objective of the food hub is to improve the sales of its farmers. An unpublished survey conducted by the Wallace Center at Winrock International states that the small producers sell 39% of their total yield by volume to a food hub. However, these small producers would like to increase this value to 63% (as mentioned Table 8). Policies 1 and 2 enable the small farmers to sell up to 34% and 38% on average to the food hub. However, with Policy 3 the small farmers can sell up to 65% of their yield to the food hub. The medium sized farmer's sale on average 38%, 32% and 45% to the food hub as per the Policy 1, Policy 2 and Policy 3 respectively and can be observed in Figure 13. The increase in sales of farmers in Policy 3 is specifically due to contractual conditions. The contractual terms of policy 3 enables farmers to sell a pre fixed quantity of produce to the food hub.

Table 8 : Producer Sales to Food hub

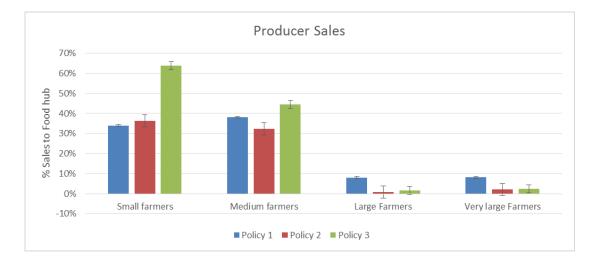| Farm Size	Survey by Wallace Center at Winrock International		Simulation Results		
	Current fh_ratio	Expected fh_ratio	Policy 1 fh_ratio	Policy 2 fh_ratio	Policy 3 fh_ratio
Small	39%	63%	34%	36%	64%
Medium	13%	30%	38%	32%	45%
Large & Very Large	8%	13%	8%	1%	2%
Sample Size	93 farmers	85 farmers	100 farmers	100 farmers	100 farmers

Figure 13: Producer Sales

Food Hub Profit

For any business to be sustainable it must generate sufficient profit. Food hub generally receives 20% of the total sales as their revenues (Huber, 2015). In this model, we consider in case the consumer receives defective produce, the food hub will refund the amount to the customer (loss). Thus the profit is difference between the revenues and the loss. As Figure 14 shows, the average food hub profit under Policies 2 and 3 is approximately 35% higher than under Policy 1. Some of this profit could be shared among the farmers, or it could be used to

reward better performing farmers. Rewarding suppliers with incentives is a common practice in manufacturing industries (Cachon, 2005). The incentives can be in the form money, fixed contracts, preferred supplier or higher prices. This practice may motivate the farmers to improve their performance and thus improving the entire supply chain and the quality of the produce. In this model, the incentives are in terms of fixed contracts (Policy 3).
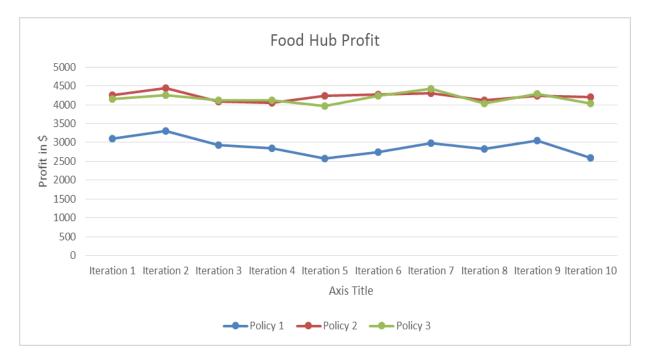

Figure 14: Food Hub Profit

Overall, Policies 2 and 3 outperform Policy 1 for almost every supply chain metric and food hub objective. These results suggest that food hub managers would greatly benefit from shifting from their status-quo of the Policy 1 to either Policy 2 or Policy 3. Policies 2 and 3 are have quite similar results for some metrics but differ with respect to the number of small farmers and medium farmers selected, the percentage of the yield supplied by small and medium sized farmers, the number of negotiations between the food hub and the farmers, and the percentage of farmers scheduling the delivery, as can be seen in Table 6. Out of the eight parameters for which the two policies differ, each policy has an advantage over the other for

four parameters. Therefore, the food hub manager would have to consider other factors (e.g., cost of negotiations, cost of administering contracts) when choosing between these two policies.

Sensitivity Analysis

Sensitivity analysis is critical to understand how robust the model is. It also gives insights into the performance of the RFSC when input parameter values are changed. In the model, the following parameters were changed one at a time and the resulting impacts on RFSC metrics were analyzed:

1. SA 1) Transportation Cost: $0.50/mile
2. SA 2) Weights on performance metric: Q = 35, D = 30, C = 25, S = 0, A = 10
3. SA 3) Weights on performance metric: Q = 20, D = 20, C = 35, S = 05, A = 20
4. SA 4) Negotiation success rate = 100%
5. SA 5) Negotiation success rate = 50%
6. SA 6) Changing contract length in Policy 3: Contract length = 30

The data and values used for the analysis are tabulated in Appendix A.

SA 1) Transportation Cost

The motivation to perform sensitivity analysis by changing the transportation cost was to understand how important the transportation cost is, in terms of sustainability of the system. This is extremely important for real-life farmers and food hubs, because fuel costs can vary widely over time.

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SA 2) Weights on farmer performance components

The original model considers farm size while rating the performance of the farmer. However, the impacts on the RFSC if size of the farmer was not considered were not known. To analyze this, the weightage on the size of the farmer was set to 0. The new weights are then:

Q = 35, D = 30, C = 25, S = 0, A = 10.

SA 3) Weights on farmer performance components

Both the literature and interviews with food hub managers clearly indicate that cost is the least important parameter with respect to RFSC performance. However it critical to consider the effects of cost on robustness of the system. The effects of a large increase in the weight on cost were of interest. The new weights are: Q = 20, D = 20, C = 35, S = 05, A = 20.

SA 4) Negotiation success rate

As mentioned earlier, it is very difficult to predict if the negotiation will be successful or not. The original model has the negotiation success rate set at 75%, but the effects of having a guaranteed 100% success rate were of interest.

SA 5) Negotiation success rate

In this analysis, the negotiation success rate is reduced to 50%.

SA 6) Changing contract length in Policy 3

In this analysis, the contract length for Policy 3 is changed from time-steps = 20 to time-steps = 30. 30 time-steps is approximately 7 months.

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Analysis

In the following sections, I discuss the sensitivity analysis performed on the three policies.

Food hub profit.

As Figure 15 shows, the food hub's profit does not show any significant changes with the changes in parameters. This is because the food hub's profit is highly dependent on demand. However, in the original model, Policy 2 results in slightly higher profits (see Figure 15). In all other model set ups, Policy 3 yields slightly higher profits. However, the difference is statistically insignificant in all cases.
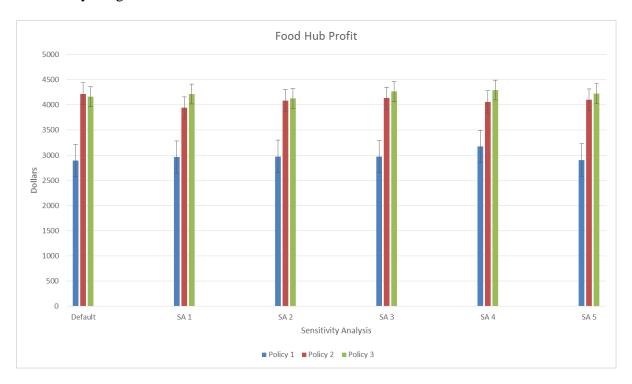

Figure 15: Food hub profit Sensitivity Analysis

Delivery

Figure 16 shows that none of the sensitivity analyses significantly affected average delivery performance.

Performance

Figure 17 shows that the average farmer performance value is not affected by any of the parameter value changes that were part of the sensitivity analysis.

Negotiation

The sensitivity analysis showed significant impacts on the average total number of negotiations conducted. As can be observed in Figure 18, increasing the transportation cost (SA 1) causes the average number of negotiations to increase for all the policies. The number of negotiation is significantly high for Policy 2. The number of negotiations increases when transportation cost is increased because the smaller farmers end up negotiating with the food hub more frequently to increase their sales (fh_ratio). When the success rate of negotiation is decreased to 50% (SA 5), there is an increase in the average required number of negotiations; however, it is not statistically significant.

Defects

The number of defects supplied by the farmers does not change significantly in any of the policies except for Policy 1, when the negotiation success rate is 50% (SA 5 in Figure 19). This is because successful negotiation is key to reduce the defects (Bora and Krejci, 2015).

fh_ratio

The percentage of sales by volume to the food hub (fh_ratio) does not change significantly for medium farmers for any of the sensitivity analysis scenarios. However, the small farmers are sensitive only to a change in transportation cost. This can be observed in Figure 20. As the transportation cost increases, the small-sized farmers want to sell more of their yield to the food hub in order to compensate for the expenses incurred due to the increase in
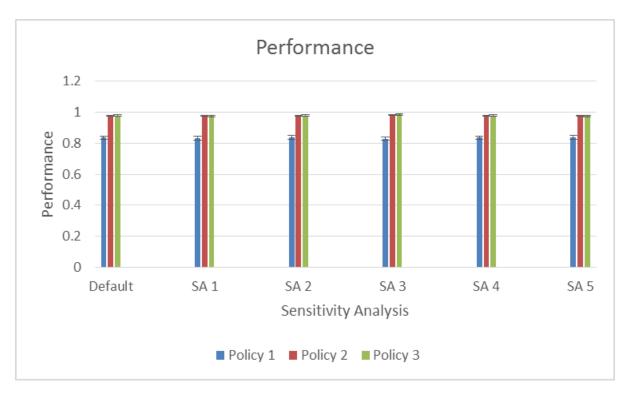
Figure 16: Delivery Sensitivity Analysis

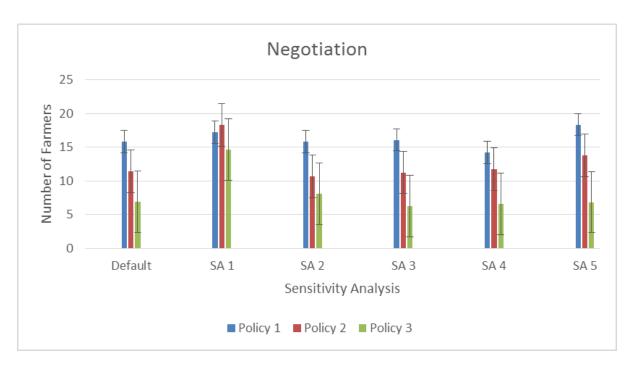*Figure 17: Performance Sensitivity Analysis*
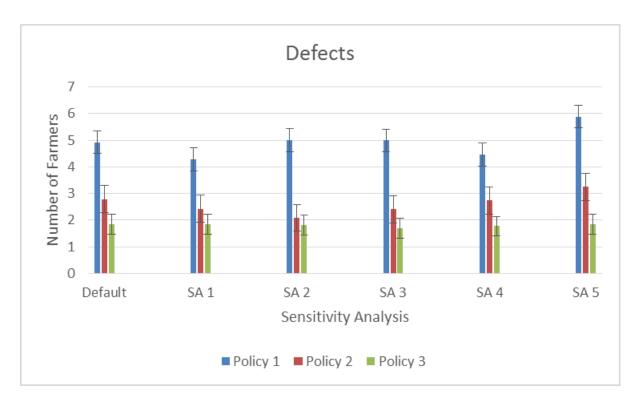
Figure 18: Negotiation Sensitivity Analysis

Figure 19: Defects Sensitivity Analysis

transportation cost. Large and very large farmers sell more to the food hub in Policy 2 and Policy 3 compared to the original model when the performance metric is altered so that the weightage on the size of farmers is low (in SA 2, S = 0% and in SA 3, S = 5%). Thus, giving a 10% weightage in the original model plays a significant role in reducing the volumes offered by large and very large farmers.

Figure 20: fh_ratio sensitivity analysis

Farmer Size Distribution

The greatest impacts of the sensitivity analysis were observed for the farmer size distribution metric. An increase in transportation cost does not affect the large and very large farmers; however, it significantly affects the number of small and medium sized farmers that are selected by the food hub manager (see Figure 21). With an increase in transportation cost, the number of small and medium sized farmers decrease. When changes are made to the weights of the performance metric, the number of large and very large farmers getting selected

increases. This change is significantly observed in Policy 2 and Policy 3. Increasing the negotiation success rate to 100% decreases the number of farmers selected; however, it is not statistically significant. Decreasing the negotiation success rate to 50% increases the number of farmers selected in Policy 2. This can be explained because the food hub needs more farmers to satisfy its demand and having large base of farmers is critical because of the low negotiation success rate.

Figure 21: Farmer Distribution Sensitivity Analysis

Changing contract length in Policy 3

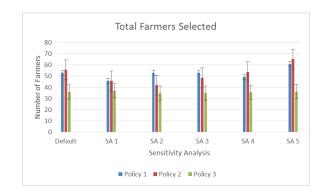The purpose of performing analysis by changing the contract length was to understand the impacts this change would have on the RFSC parameters. In this sensitivity analysis, the contract length is set as 30 time-steps. Changing the contract length in policy 3 has no significant effect on any of the RFSC metrics.

Conclusion

This thesis described a multi-agent simulation model of a theoretical food-producing region in which farmers of various sizes negotiate with and sell food to a regional food hub. This model was used to assess the impact of three different supplier selection policies on performance and structural metrics of the regional food system, which is an area of significant interest to food hub managers and other regional food chain participants. The use of multi-agent simulation to study this problem allowed agent autonomy and heterogeneity to be captured, in terms of objectives, attributes, and behavior. It also enables food hub managers to be represented as decision makers who apply multiple different criteria (including non-traditional social metrics) in their evaluation of supplier performance, as they do in the real world.

Among the three different policies analyzed in this model, Policy 2 and Policy 3 perform much better than Policy 1 overall, although each policy has its own advantages. With Policy 3, each selected farmer is able to earn higher profits; however, there are fewer farmers selected compared to Policy 2. One of the reasons that the average amount of produce sold to food hub (fh_ratio) by small farmers in Policy 2 is similar to Policy 1 is that the farmer calculates his sales as per his multi-objective utility value (i.e., if the farmer is

satisfied with the current sales, he would not sell more, even if it would mean more profits). This is a result of the risk-averse behavior that has been observed in most farmers. However, some farmers do achieve a higher fh_ratio (up to 80%). In cases where a small farmer is located far away from the food hub, the farmer needs to sell a higher percentage of its produce (fh_ratio) to compensate for the transportation cost incurred of delivering produce to the food hub. With Policy 3, due to the food hub's assurance of the contract length and volume (fh_ratio), the farmer feels secure in selling his produce. The assurance of food hub purchasing a fixed volume of produce for a fixed term, serves as an assurance. This assurance helps farmer to trust the food hub and build a healthy relationship. Thus we can conclude that Policy 3 helps in overcoming the risk averse behavior of farmers by assuring them consistent sales.

The results of our experiments indicate that food hubs should anticipate that an up-front investment of time and resources will be necessary to provide adequate assistance to smaller-scale farmers to help them meet performance requirements. However, once these relationships have been established, food hubs, regional farmers, and consumers can greatly benefit from this partnership. For example, to set up a process to measure farmers' performance requires informing all the about the process. In some cases give them training on how their performance can be improved. As can be seen from Figure 11 for Policy 3, the % of farmers with whom the negotiations are conducted is greater than the other policies for first 40 time-steps. However once the process is set, the number of negotiations are then significantly less. Outputs from the experiments indicate that consistency of suppliers is key for the success of Policy 2 and Policy 3. Since the same farmers are consistently selected in

Policy 2 and Policy 3, future research to assess whether coordination among the selected farmers could be achieved would be of interest.

Coordination among selected farmers has the potential to reduce the transportation requirements of the individual farmers and benefit the RFSC overall. . As can be seen in Figure 22, the number of farmers selected more than 95% of the time is 31. Close observation indicates small groups of 3-5 farmers tend to emerge that have the potential to coordinate among themselves to transport their products to the food hub (see Figure 23). This type of coordination could reduce the total transportation (i.e., "food miles") by one-third. Also, as the results of the sensitivity analysis indicate, transportation cost is a critical factor for the RFSC. Reductions in transportation costs can help reduce the cost of the food. This will help reduce the perception and the generally observed trend of regionally-produced food as being expensive compared to the conventional food supply chain. Another potential benefit is reduction in emission of greenhouse gases.

The outcomes of this research can provide guidance to food hub managers as they develop their supply chain management policies to support profitable, efficient, and sustainable regional food chains. One limitation of this model is that it only captures the production and distribution of a single crop type. It would be interesting to see how the agents would perform with multiple crops. Also, the distribution of demand is assumed to be static, such that steep growth or decline in demand is not considered. A possible future development of the model presented in this thesis is the inclusion of multiple (possibly competing) food hubs. In particular, it would be interesting to model multiple food hubs with each food hub having different business models and/or sets of objectives.

Figure 22: Farmer Selection

Figure 23:Policy 2 Farmer Selection and Location

This model can be used as a basis for understanding the impacts of supplier selection policies in RFSCs and provides a starting point for future experiments that could include empirical data from real-life RFSCs and food hubs. For example, food hub managers can capture farmers' performanc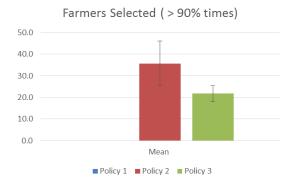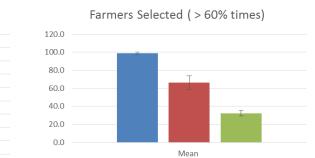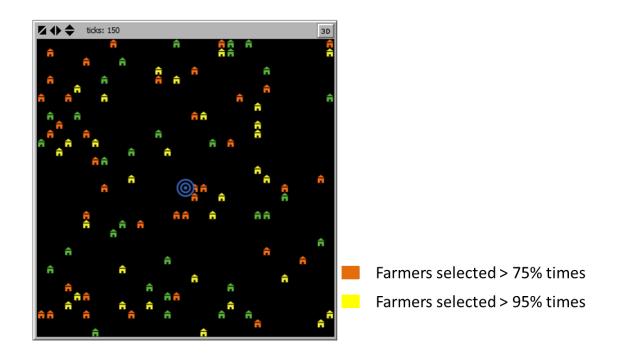e using a version of a Balanced Scorecard that is tailored to the needs of an RFSC (see Appendix for an example of such a tool that is currently being piloted by food hubs in Iowa). Overall, the outcomes of the experiments described in this thesis match the expectations that are suggested in the RFSC literature, and their implications have the potential to immensely help food hub managers to implement one a selection policy such as Policy 2 or Policy 3.

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CHAPTER 3

GENERAL CONCLUSIONS

General Discussion

This thesis described a multi-agent simulation model of a theoretical food-producing region

in which farmers of various sizes negotiate with and sell food to a regional food hub. This

model was used to assess the impact of three different supplier selection policies on

performance and structural metrics of the regional food system, which is an area of

significant interest to food hub managers and other regional food chain participants. The use

of multi-agent simulation to study this problem allowed agent autonomy and heterogeneity to

be captured, in terms of objectives, attributes, and behavior. It also enables food hub

managers to be represented as decision makers who apply multiple different criteria

(including non-traditional social metrics) in their evaluation of supplier performance, as they

do in the real world.

Among the three different policies analyzed in this model, Policy 2 and Policy 3

perform much better than Policy 1 overall, although each policy has its own advantages.

With Policy 3, each selected farmer is able to earn higher profits; however, there are fewer

farmers selected compared to Policy 2. One of the reasons that the average amount of

produce sold to food hub (fh_ratio) by small farmers in Policy 2 is similar to Policy 1 is that

the farmer calculates his sales as per his multi-objective utility value (i.e., if the farmer is

satisfied with the current sales, he would not sell more, even if it would mean more profits).

This is a result of the risk-averse behavior that has been observed in most farmers. However,

some farmers do achieve a higher fh_ratio (up to 80%). In cases where a small farmer is

located far away from the food hub, the farmer needs to sell a higher percentage of its

produce (fh_ratio) to compensate for the transportation cost incurred of delivering produce to the food hub. With Policy 3, due to the food hub's assurance of the contract length and volume (fh_ratio), the farmer feels secure in selling his produce. The assurance of food hub purchasing a fixed volume of produce for a fixed term, serves as an assurance. This assurance helps farmer to trust the food hub and build a healthy relationship. Thus we can conclude that Policy 3 helps in overcoming the risk averse behavior of farmers by assuring them consistent sales.

<div align="center">**Recommendation for future work**</div>

The results of our experiments indicate that food hubs should anticipate that an up-front investment of time and resources will be necessary to provide adequate assistance to smaller-scale farmers to help them meet performance requirements. However, once these relationships have been established, food hubs, regional farmers, and consumers can greatly benefit from this partnership. For example, to set up a process to measure farmers' performance requires informing all the about the process. In some cases give them training on how their performance can be improved. As can be seen from Figure 11 for Policy 3, the % of farmers with whom the negotiations are conducted is greater than the other policies for first 40 time-steps. However once the process is set, the number of negotiations are then significantly less. Outputs from the experiments indicate that consistency of suppliers is key for the success of Policy 2 and Policy 3. Since the same farmers are consistently selected in Policy 2 and Policy 3, future research to assess whether coordination among the selected farmers could be achieved would be of interest.

Coordination among selected farmers has the potential to reduce the transportation requirements of the individual farmers and benefit the RFSC overall. As can be seen in Figure 22, the number of farmers selected more than 95% of the time is 31. Close observation indicates small groups of 3-5 farmers tend to emerge that have the potential to coordinate among themselves to transport their products to the food hub (see Figure 23). This type of coordination could reduce the total transportation (i.e., "food miles") by one-third. Also, as the results of the sensitivity analysis indicate, transportation cost is a critical factor for the RFSC. Reductions in transportation costs can help reduce the cost of the food. This will help reduce the perception and the generally observed trend of regionally-produced food as being expensive compared to the conventional food supply chain. Another potential benefit is reduction in emission of greenhouse gases.

Limitations of the Study

The outcomes of this research can provide guidance to food hub managers as they develop their supply chain management policies to support profitable, efficient, and sustainable regional food chains. One limitation of this model is that it only captures the production and distribution of a single crop type. It would be interesting to see how the agents would perform with multiple crops. Also, the distribution of demand is assumed to be static, such that steep growth or decline in demand is not considered. A possible future development of the model presented in this thesis is the inclusion of multiple (possibly competing) food hubs. In particular, it would be interesting to model multiple food hubs with each food hub having different business models and/or sets of objectives.

This model can be used as a basis for understanding the impacts of supplier selection policies in RFSCs and provides a starting point for future experiments that could include

empirical data from real-life RFSCs and food hubs. For example, food hub managers can capture farmers' performance using a version of a Balanced Scorecard that is tailored to the needs of an RFSC (see Appendix for an example of such a tool that is currently being piloted by food hubs in Iowa). Overall, the outcomes of the experiments described in this thesis match the expectations that are suggested in the RFSC literature and their implications have the potential to immensely help food hub managers to implement one a selection policy such as Policy 2 or Policy 3.

APPENDIX A. SENSITIVITY ANALYSIS DATA

Data of sensitivity analysis in tabular form.

Delivery

	Policy 1	Policy 2	Policy 3
Default	67.16667	99.59867	93.18933
Std Dev	1.662142	0.430467	1.568817
SA 1	66.76933	98.47733	94.70533
Std Dev	1.975645	1.453962	1.943737
SA 2	67.63467	99.49467	93.67467
Std Dev	2.398594	0.742008	1.280281
SA 3	67.37467	99.39467	93.58933
Std Dev	2.496247	0.635484	1.866379
SA 4	66.54533	99.40533	95.364
Std Dev	2.147145	0.644956	2.184507
SA 5	68.30667	99.71067	90.59067
Std Dev	2.347862	0.302748	1.338775

Negotiation

	Policy 1	Policy 2	Policy 3
Default	15.86533	11.432	6.946667
Std Dev	0.936196	2.395858	1.355577
SA 1	17.25067	18.31733	14.644
Std Dev	0.597007	3.161883	4.561118
SA 2	15.84133	10.696	8.118667
Std Dev	0.818465	1.896177	1.886063
SA 3	16.11867	11.27867	6.249333
Std Dev	1.074002	1.375187	0.963718
SA 4	14.24667	11.78	6.585333
Std Dev	0.615303	2.316261	2.084738
SA 5	18.35333	13.808	6.873333
Std Dev	1.636452	2.372802	2.061094

Performance

	Policy 1	Policy 2	Policy 3
Default	83.54%	97.88%	97.81%
Std Dev	0.77%	0.20%	0.23%
SA 1	83.38%	97.65%	97.70%
Std Dev	0.76%	0.30%	0.31%
SA 2	83.75%	97.80%	97.92%
Std Dev	1.15%	0.27%	0.22%
SA 3	82.96%	98.43%	98.61%
Std Dev	0.75%	0.17%	0.09%
SA 4	83.67%	97.87%	97.95%
Std Dev	0.70%	0.23%	0.32%
SA 5	83.86%	97.68%	97.60%
Std Dev	0.71%	0.23%	0.51%

Defects

	Policy 1	Policy 2	Policy 3
Default	4.925333	2.781333	1.849333
Std Dev	0.285636	0.478359	0.228623
SA 1	4.281333	2.418667	1.856
Std Dev	0.194385	0.412027	0.374696
SA 2	5.001333	2.084	1.808
Std Dev	0.427381	0.504089	0.273772
SA 3	4.997333	2.409333	1.704
Std Dev	0.298725	0.401334	0.229033
SA 4	4.466667	2.736	1.769333
Std Dev	0.144291	0.508837	0.343061
SA 5	5.885333	3.245333	1.842667
Std Dev	0.405552	0.345193	0.335242

Food hub profit

	Policy 1	Policy 2	Policy 3
Default	2896.254	4219.656	4166.106
Std Dev	229.1847	113.0977	139.8804
SA 1	2962.483	3942.843	4217.789
Std Dev	245.7015	168.6844	196.9528
SA 2	2978.072	4085.152	4132.398
Std Dev	320.695	182.2455	194.5683
SA 3	2971.233	4135.651	4265.996
Std Dev	298.3855	220.6918	181.2612
SA 4	3174.443	4058.186	4294.221
Std Dev	213.7696	137.7713	187.5049
SA 5	2907.837	4099.323	4230.386
Std Dev	301.9559	139.9251	138.5932

Fh_ratio Small Farmers

	Policy 1	Policy 2	Policy 3
Default	0.339627	0.36292	0.638667
Std Dev	0.002485	0.02075	0.007387
SA 1	0.500187	0.518107	0.640453
Std Dev	0.008157	0.021174	0.008277
SA 2	0.338947	0.365467	0.64156
Std Dev	0.00424	0.037758	0.006256
SA 3	0.336813	0.380813	0.648187
Std Dev	0.005854	0.024034	0.003154
SA 4	0.341613	0.379253	0.644467
Std Dev	0.00502	0.016693	0.006841
SA 5	0.33696	0.35728	0.629947
Std Dev	0.005308	0.020088	0.012475

Fh_ratio Medium farmers

	Policy 1	Policy 2	Policy 3
Default	0.381573	0.322393	0.445627
Std Dev	0.007945	0.01939	0.003011
SA 1	0.390307	0.355733	0.44364
Std Dev	0.000576	0.026759	0.009711
SA 2	0.383187	0.32468	0.443987
Std Dev	0.006782	0.02441	0.003434
SA 3	0.38132	0.324613	0.448133
Std Dev	0.004699	0.021814	0.002045
SA 4	0.390387	0.344027	0.44392
Std Dev	0.000528	0.025289	0.00783
SA 5	0.333933	0.289053	0.444067
Std Dev	0.019036	0.023077	0.007832

Fh_ratio Large Farmers

	Policy 1	Policy 2	Policy 3
Default	0.08032	0.00744	0.016173
Std Dev	0.0049	0.011333	0.010079
SA 1	0.074307	0.013853	0.02368
Std Dev	0.004113	0.019802	0.023017
SA 2	0.081827	0.083653	0.087333
Std Dev	0.003738	0.018576	0.029654
SA 3	0.08312	0.070907	0.019987
Std Dev	0.005435	0.037685	0.025586
SA 4	0.101133	0.012827	0.007507
Std Dev	0.005322	0.023976	0.007987
SA 5	0.060147	0.02528	0.00952
Std Dev	0.003418	0.022361	0.006947

Fh_Ratio Very Large Farmers

	Policy 1	Policy 2	Policy 3
Default	0.080973	0.02064	0.024893
Std Dev	0.004174	0.028269	0.015599
SA 1	0.07876	0.018253	0.017093
Std Dev	0.004614	0.038526	0.020043
SA 2	0.08364	0.091133	0.08872
Std Dev	0.003341	0.002963	0.031654
SA 3	0.0822	0.072347	0.03416
Std Dev	0.004607	0.038198	0.038012
SA 4	0.106147	0.021493	0.020373
Std Dev	0.005497	0.038102	0.022517
SA 5	0.060747	0.025227	0.015453
Std Dev	0.002567	0.027047	0.020174

Total Selected farmers

	Policy 1	Policy 2	Policy 3
Default	52.90	55.73	35.96
Std Dev	1.30	7.99	3.31
SA 1	45.78	45.68	37.02
Std Dev	0.68	5.61	5.91
SA 2	53.15	41.93	34.73
Std Dev	1.22	8.93	5.67
SA 3	53.20	48.52	34.88
Std Dev	1.00	6.58	3.91
SA 4	49.13	53.79	35.65
Std Dev	0.57	8.21	6.27
SA 5	60.97	65.33	36.16
Std Dev	2.17	4.77	6.37

Small Farmers

	Policy 1	Policy 2	Policy 3
Default	41.48	43.58	29.90
Std Dev	1.19	8.54	3.28
SA 1	35.93	36.13	30.34
Std Dev	0.67	5.50	6.14
SA 2	41.80	28.01	27.34
Std Dev	1.23	9.22	6.55
SA 3	41.82	35.73	27.83
Std Dev	0.92	6.72	4.10
SA 4	38.44	42.42	29.39
Std Dev	0.61	8.24	6.59
SA 5	47.80	52.26	28.66
Std Dev	1.70	4.66	7.24

Medium Farmers

	Policy 1	Policy 2	Policy 3
Default	8.15	11.75	5.50
Std Dev	0.16	1.22	0.59
SA 1	7.03	8.98	6.11
Std Dev	0.18	0.78	0.91
SA 2	8.09	10.49	4.81
Std Dev	0.16	0.75	1.87
SA 3	8.13	10.63	6.48
Std Dev	0.17	1.26	1.10
SA 4	7.64	11.00	5.94
Std Dev	0.10	0.73	0.84
SA 5	9.39	12.00	6.96
Std Dev	0.32	0.82	1.29

Large Farmers

	Policy 1	Policy 2	Policy 3
Default	1.63	0.12	0.20
Std Dev	0.14	0.18	0.14
SA 1	1.39	0.20	0.31
Std Dev	0.10	0.28	0.27
SA 2	1.60	1.47	1.33
Std Dev	0.10	0.48	0.90
SA 3	1.63	0.96	0.23
Std Dev	0.10	0.60	0.31
SA 4	1.50	0.15	0.09
Std Dev	0.12	0.25	0.10
SA 5	1.89	0.56	0.25
Std Dev	0.14	0.54	0.25

Very Large Farmers

	Policy 1	Policy 2	Policy 3
Default	1.64	0.28	0.36
Std Dev	0.10	0.36	0.32
SA 1	1.42	0.38	0.25
Std Dev	0.09	0.80	0.25
SA 2	1.65	1.97	1.24
Std Dev	0.05	0.47	0.65
SA 3	1.62	1.20	0.34
Std Dev	0.13	0.79	0.39
SA 4	1.55	0.22	0.23
Std Dev	0.10	0.37	0.24
SA 5	1.89	0.51	0.29
Std Dev	0.14	0.48	0.36

APPENDIX B. USERFORM FOR IOWA FOOD CO-OP

Userform for Iowa Food Coop Des Moines. The following figures give an overview of how

the data for farmers is captured using the userform in MS Excel.

The following figure gives a dashboard overview of the various important metric for the food hub.

DashBoard

Legend: 16-Jul-15, 30-Jul-15, 13-Aug-15, 27-Aug-15

Categories: Number of Producers, # of Producers Scheduled, # of Producers Late, # of Producers with Quantity Issues, # of Producers with Labeling Issues, # of Producers with Packaging Issues, # of Producers with Quality Issues