Analysis of Grain Supply Chain Performance Based on Relative Impact of Channel Coordinator's Objectives on Firm Level Objectives

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Abstract

Trend towards vertical coordination presents new economic challenges in modeling and analyzing ways of coordinating value-creating activities in supply chains. This study focuses on how to model and analyze alignment of conflicting goals and to prioritize goals in multi-objective vertically coordinated systems. Specifically, this study analyzes the optimal decisions of a multi-objective grain supply chain in which the profit maximization objectives of the production, storage, and processing level firms are conflicting with the channel coordinator's cost minimization goals associated with quality assurance, quantity reliability, and transaction costs among firms in the supply chain. Furthermore, a linear weighting method is used to prioritize (using optimal weights) the channel coordinator's goals to reflect their relative impact on firm level decisions and the overall performance of the supply chain. Two analyses are conducted using fuzzy linear programming. The first analysis models the supply chain problem with equally weighted channel coordinator's goals while the second analysis incorporates optimal weights for the channel coordinator to reflect their relative importance. The main conclusion of the study is that prioritizing the channel coordinator's goals in a grain the supply chain enhances the overall performance of the system but not by very significant amounts.

Key Words: Multi-objective optimization, grain supply chain, supply channel coordination, linear weighting method, fuzzy linear programming, supply chain performance

Introduction

U.S. food and fiber systems are transforming into vertically coordinated systems similar to supply chains of other industries. Trends towards vertical coordination present new economic challenges in modeling and analysis of efficient ways of coordinating value-creating activities. Two such challenges involve alignment of conflicting goals and prioritizing goals in multi-objective vertically coordinated systems.

Conflicts in supply chains may arise from differences in perceptions about the competing priorities of the system. This is confounded by interdependence between feasible alternatives, which could enhance the adverse effects of externalities and could potentially lead to sub-optimal supply chain performance. Furthermore, because firms are maximizers of their utilities, they may not have the incentive to perform functions that do not directly impact their outcomes. Thus, the role of a channel coordinator is important to manage conflicts and to perform non-firm specific functions in order to synergize complementary activities across the supply chain. King (2002) observed that one key driver of a supply chain structure is the locus and strength of channel leadership, which could influence the overall chain structure, the nature of interaction, product and information flows, and distribution of returns and costs.

This study focuses on a multi-objective decentralized controlled grain supply chain problem in which the priority of the production, storage, and processing level firms are conflicting with those of the channel coordinator. That is the decisions of the production, storage, and processing level firms are to maximize profits of their operations while the channel coordinator's goals minimize transaction costs, product quality costs, and supply reliability costs that are associated with the flow of commodities and interaction between firms across the system. Those channel coordinator's costs have been identified as important in identity preserved grain supply chain (Maltsbarger and Kalaitzandonakes, 2000). Furthermore, the overall impact of the channel coordinator's goals may not equally impact the overall performance of the systems. This underscores the need to examine the relative impact of those costs on the performance of the grain supply chain.

The study adopts a fuzzy multi-objective linear programming to analyze the grain supply chain problem for five reasons: First, the procedure is capable of modeling a system that consists of conflicting objectives. Secondly, it generates compromise solutions from simultaneous optimization of sub-problems for firms that operate in the different levels of the systems.

Accordingly it generates optimal solutions for each firm's sub-problem and thus provides information on how income is distributed in the systems. Third, the compromise solutions are based on tradeoffs between the membership functions of the sub-problems. This implies that the compromise solutions are reached through cooperative relationships, thus the compromise solutions are fair and equitable. Fourth, the membership functions incorporate uncertainty in the sub-problems through tolerance intervals. This implicitly suggests that the optimal decisions accounts for uncertainties in the supply chain environment and that the optimal tradeoff decisions distributes risks within the systems. Finally, the procedure reports global achievement levels, which measures the overall level of satisfaction in the compromise solutions. This is used as an additional criterion to compare the performances of the spans of control designs.

The two specific objectives of this study are: 1) to determine the costs and profit distributions among firms and the channel coordinator in a decentralized control grain supply chain, and 2) to evaluate the relative impact of the channel coordinator's goals on the performance of the grain supply chain. Two analyses are conducted and compared to determine whether prioritizing the channel coordinator's goals enhances the performance of the grain supply chain. The first analysis assumes that that channel coordinator's goals are equally important and is analyzed with equal weights. The second analysis assumes that the channel coordinator's goals have unequal importance. A linear weighting method is to determine a priority structure based on their optimal weights. Performances of the two analyses are compared in terms of total firm level profits, total supply chain profits, channel coordinator's costs, net supply chain profits, and the global achievement levels.

The rest of the paper is organized as follows: Section Two covers the theoretical framework on fuzzy multi-objective linear programming and the linear weighting method used to determine optimal weights. Section Three covers the description and mathematical formulation of the multi-objective grain supply chain problem. Section Four covers data sources and model parameterization. Section Five discusses the results and the final section concludes the study.

2. Theoretical Framework

Consider a three level grain supply chain problem consisting of i production level firms where $(i = 1,2,...,I)$; j storage level firms where $(j = 1,2,...,J)$; k processing level firms where $(k = 1,2,...,K)$, and s channel coordinator's objectives where $(s = 1,2,...,S)$. The fuzzy multi-objective programming problem in which uncertainty is defined in the objective functions is defined as follows:

$$\begin{aligned}
&\text{Production Level Objectives}\\
&\textit{Maximize } (\tilde{Z}x)_i = \left[(\tilde{Z}x)_1, (\tilde{Z}x)_2, ..., (\tilde{Z}x)_I\right]^T\\
&\text{Storage Level Objectives}\\
&\textit{Maximize } (\tilde{Z}x)_j = \left[(\tilde{Z}x)_1, (\tilde{Z}x)_2, ..., (\tilde{Z}x)_J\right]^T\\
&\text{Processing Level Objectives}\\
&\textit{Maximize } (\tilde{Z}x)_k = \left[(\tilde{Z}x)_1, (\tilde{Z}x)_2, ..., (\tilde{Z}x)_K\right]^T\\
&\text{Chnanel Coordinator's Objectives}\\
&\textit{Minimize } (\tilde{Z}x)_s = \left[(\tilde{Z}x)_1, (\tilde{Z}x)_2, ..., (\tilde{Z}x)_S\right]^T\\
&\textit{Subject to}\\
&x \in X = \left\{x_{ijks} \middle| (Ax)_i + (Ax)_j + (Ax)_k + (Ax)_s (\ast) B_{ijks}, x_{ijks} \geq 0\right\}
\end{aligned} \tag{1}$$

Where $(x_{i,j,k,s})$ is an n dimensional vectors of decision variables, $(\sim)$ represents fuzzy objective functions, $(\ast)$ is an operator that can take either $(\leq, =, \geq)$ sign in the constraints, $x \in X$ represent the complete set of crisp supply chain constraints, B_{ijks} are m dimensional constant vectors for available resources, and $(Ax)_{i,j,k,s}$ are mXn matrices for technological coefficients.

Uncertainties in the objective functions in (1) are incorporated in the analysis by constructing linear non-decreasing objective membership functions for the firm level maximization objectives and non-increasing membership functions for minimization objectives of the channel coordinator's goals. While the shape of the membership functional forms can be either linear or non-linear, this study like most fuzzy linear programming applications use linear membership functional form because of its computational simplicity. Ideally, the tolerance intervals of the objective membership functions should be constructed interactively with experiences decision-makers or experts of the system, which was not accomplished in this study. Following Zimmermann (1978), the tolerance intervals of the firm level and channel coordinator's goals are determined by estimating the upper bounds or ideal solutions $(Z^{*}_{i,j,k})$ and the lower bounds or anti-ideal solutions $(Z^{-}_{i,j,k})$ for the maximization problems and vise versa for the minimization problems. The tolerance intervals of the firm level maximization objectives are obtained by solving the following:

$$\begin{array}{ll} Z^{*}_{i,j,k} = \max (Zx)_{i,j,k} \ \forall i,j,k & \quad Z^{-}_{i,j,k} \ \min (Zx)_{i,j,k} \ \forall i,j,k \\ s.t. & \quad s.t. \\ (Ax)_{i,j,k}(\circ)B_{i,j,k} & \quad (Ax)_{i,j,k}(\circ)B_{i,j,k} \end{array} \qquad (2a)$$

In the case of the channel coordinator's minimization goals, the tolerance intervals are obtained by solving the following:

$$\begin{array}{ll} Z^{*}_{i,j,k} = \min (Zx)_{i,j,k} \ \forall i,j,k & \quad Z^{-}_{i,j,k} \ \max (Zx)_{i,j,k} \ \forall i,j,k \\ s.t. & \quad s.t. \\ (Ax)_{i,j,k}(\circ)B_{i,j,k} & \quad (Ax)_{i,j,k}(\circ)B_{i,j,k} \end{array} \qquad (2b)$$

Using the tolerance intervals, the linear objective membership functions expressing the degrees of individual optimalities for the maximization and minimization objectives are mathematically expressed as follows:

Maximization Objectives

$$\mu_{i,j,k}(Z_{i,j,k}) = \begin{cases} 1, & if\ (Zx)_{i,j,k} > Z^{*}_{i,j,k} \\ \dfrac{(Zx)_{i,j,k} - Z^{-}_{i,j,k}}{Z^{*}_{i,j,k} - Z^{-}_{i,j,k}}, & if\ Z^{-}_{i,j,k} \le (Zx)_{i,j,k} \le Z^{*}_{i,j,k} \\ 0, & if\ (Zx)_{i,j,k} < Z^{-}_{i,j,k} \end{cases} \quad (3a)$$

$$\forall i = 1,2,\ldots,I;\ j = 1,2,\ldots,J\ and\ k = 1,2,\ldots,K$$

Minimization Objectives

$$\mu_{s}(Z_{s}) = \begin{cases} 1, & if\ (Zx)_{s} > Z^{*}_{s} \\ \dfrac{Z^{*}_{s} - (Zx)_{s} -}{Z^{*}_{s} - Z^{-}_{s}}, & if\ Z^{-}_{s} \le (Zx)_{s} \le Z^{*}_{s} \\ 0, & if\ (Zx)_{s} < Z^{-}_{s} \end{cases} \quad (3b)$$

$$\forall s = 1,2,\ldots,S$$

Zimmermann (1978) first illustrated that the fuzzy multi-objective linear programming problem in (1) can be converted into a standard linear programming problem by first introducing an auxiliary variable (λ) and then applying the Bellman and Zadeh (1970) min-operator. The resulting standard linear programming problem is specified as follows:

$$\begin{aligned} & Max\ \lambda \\ & Subject\ to \\ & x \in X \\ & \mu_{i}(Zx)_{i} = \tfrac{(Zx)_{i} - Z^{-}_{i}}{Z^{*}_{i} - Z^{-}_{i}} \ge \lambda_{i} \quad \forall i \\ & \mu_{j}(Zx)_{j} = \tfrac{(Zx)_{j} - Z^{-}_{j}}{Z^{*}_{j} - Z^{-}_{j}} \ge \lambda \quad \forall j \\ & \mu_{k}(Zx)_{k} = \tfrac{(Zx)_{k} - Z^{-}_{k}}{Z^{*}_{k} - Z^{-}_{k}} \ge \lambda \quad \forall k \\ & \mu_{s}(Zx)_{s} = \tfrac{Z^{*}_{s} - (Zx)_{s}}{Z^{*}_{i} - Z^{-}_{i}} \ge \lambda \quad \forall s \\ & \lambda \in [0,1] \end{aligned} \quad (4)$$

While the min operator is widely used in fuzzy linear programming applications, it is limited in that it may not allow tradeoffs between high and low degrees of memberships (Zimmermann, 1991). The "fuzzy and" operator (Werners, 1987) is a compensatory operator that addresses the shortcomings of the min operator. Lee and Shih (2001) noted that the "fuzzy and" operator generates reasonably consistent results in applications. Using the "fuzzy and" operator, (4) is redefined as

$$
\begin{aligned}
&Max\ \mu_{and} = \lambda + (1-\gamma)\frac{1}{I+J+K+S}\left[\sum_{i=1}^{I}\lambda_i + \sum_{j=1}^{J}\lambda_j + \sum_{k=1}^{K}\lambda_k + S\left(\sum_{s=1}^{S}\frac{1}{S}w_s\lambda_s\right)\right] \\
&Subject\ to \\
&x \in X \\
&\mu_i(Zx)_i = \tfrac{(Zx)_i - Z_i^-}{Z_i^* - Z_i^-} \geq \lambda + \lambda_i \quad \forall i \\
&\mu_j(Zx)_j = \tfrac{(Zx)_j - Z_j^-}{Z_j^* - Z_j^-} \geq \lambda + \lambda_j \quad \forall j \\
&\mu_k(Zx)_k = \tfrac{(Zx)_k - Z_k^-}{Z_k^* - Z_k^-} \geq \lambda + \lambda_k \quad \forall k \\
&\mu_s(Zx)_s = \tfrac{Z_s^* - (Zx)_s}{Z_i^* - Z_i^-} \geq \lambda + \lambda_s \quad \forall s \\
&\lambda + \lambda_i \leq 1 \quad \forall i \\
&\lambda + \lambda_j \leq 1 \quad \forall j \\
&\lambda + \lambda_k \leq 1 \quad \forall k \\
&\lambda + \lambda_s \leq 1 \quad \forall s \\
&\lambda\ and\ \gamma \in [0,1] \qquad (4)
\end{aligned}
$$

Where μ_r are the membership functions for $(r = i, j, k, s)$ defined in the interval ($0 \leq \mu_r \leq 1$), γ is the degree of compensation defined within the interval ($0 \leq \gamma \leq 1$), w_s are the optimal weights for the channel coordinator's objectives, which must satisfy the condition $\sum w_s = 1$. In the first analysis in which the channel coordinator's objectives are of equal importance, the transaction costs, product quality costs, and supply reliability costs are equally weighted in the objective function. That is, the weighted portion of the objective function involving the channel coordinator's goals is defined as $w_s = 3 * \frac{1}{3}(\lambda_1 + \lambda_2 + \lambda_3)$.

In the second analysis, the optimal weights of the channel coordinator's goals are computed using Saaty's (1982) eigenvector method. The procedure is refined to deal with the specific problem addressed in this study. Let the vector of the channel coordinator's ideal solutions be defined as $(Z_s^* = Z_1^*, Z_2^*, ..., Z_S^*)^T$ and their corresponding optimal weights be represented by $(w_s^* = w_1^*, w_2^*, ..., w_S^*)^T$. The pair wise comparison matrix is defined as

$$Z_s = \underbrace{\begin{bmatrix} \frac{Z_1^*}{Z_1^*} & \frac{Z_1^*}{Z_2^*} & : & \frac{Z_1^*}{Z_S^*} \\ \frac{Z_2^*}{Z_1^*} & \frac{Z_2^*}{Z_2^*} & : & \frac{Z_2^*}{Z_S^*} \\ : & : & : & : \\ \frac{Z_S^*}{Z_1^*} & \frac{Z_S^*}{Z_2^*} & : & \frac{Z_S^*}{Z_S^*} \end{bmatrix}}_{A} = \underbrace{\begin{bmatrix} z_{11} & z_{12} & : & z_{1S} \\ z_{21} & z_{22} & : & z_{2S} \\ : & : & : & : \\ z_{S1} & z_{S2} & : & z_{SS} \end{bmatrix}}_{B} \tag{5}$$

Where matrix A is a reciprocal matrix that has the property $z_{ij} = 1/z_{ji}$ and $z_{ij} = z_{ik}/z_{jk}$. Matrix B is composed of positive elements resulting from the pair wise comparison operation. Next we set the determinant of $(Z_s - \alpha I) = 0$ such that matrix B is now defined as follows

$$\det(Z_s - \alpha I) = \underbrace{\begin{bmatrix} z_{11} - \alpha & z_{12} & : & z_{1S} \\ z_{21} & z_{22} - \alpha & : & z_{2S} \\ : & : & : & : \\ z_{S1} & z_{S2} & : & z_{SS} - \alpha \end{bmatrix}}_{C} = 0 \tag{6}$$

Where α is the largest Eigen value of Z_S. The corresponding eigenvector is obtained by multiplying matrix C by the vector of weights to obtain the following equation

$$Z_s w_s = \underbrace{\begin{bmatrix} z_{11}-\alpha & z_{12} & : & z_{1S} \\ z_{21} & z_{22}-\alpha & : & z_{2S} \\ : & : & : & : \\ z_{S1} & z_{S2} & : & z_{SS}-\alpha \end{bmatrix}}_{C} * \begin{bmatrix} w_1 \\ w_2 \\ : \\ w_S \end{bmatrix} = 0 \qquad (7)$$

Notice that the elements of matrix C are estimated numbers and the vector of weights are variables. Thus, equation (7) is a system of linear equations, which can be solved simultaneously to obtain the optimal weights. The simultaneous equations are explicitly defined as follows

$$\begin{aligned} (z_{11}-\alpha)w_1 \; + \; z_{12}w_2 \; +,\ldots,+ \; z_{1S}w_S &= 0 \\ z_{21}w_1 \; + \; (z_{22}-\alpha)w_2 \; +,\ldots,+ \; z_{2S}w_S &= 0 \\ : \qquad : \qquad : \qquad & : \\ z_{S1}w_1 \; + \; z_{S2}w_2 \; +,\ldots,+ \; (z_{SS}-\alpha)w_S &= 0 \\ w_1 \; + \; w_2 \; +,\ldots,+ \; w_S &= 1 \end{aligned} \qquad (8)$$

The last constraint in (8) is incorporated to satisfy the requirement that the sum of the weights in the linear weighted objective function should equal to one. The optimal weights obtained in (8) are then incorporated in (4) such that its solution reflects the relative importance of the channel coordinator's objectives.

3. Description and Mathematical Formulations of Grain Supply Chain Problems

Coordination of the grain supply chain within a marketing year (time horizon) is largely achieved through market prices. Price risks are managed through contracts, which specify terms of expected future prices with the primary objective to transfer price risks from one firm to another or between the stages of the supply chain. Considering the importance of the temporal dimension in grain supply chain decision-making, the grain supply chain problem is modeled as a multi-period problem such that the optimal decisions of the systems are based on temporal reactions to prices. Three four-month time periods within the planning horizon are used to define the average prices of the systems.

A representative grain supply chain is analyzed that consists of a channel coordinator and fourteen firms with ten firms that produce corn and soybeans at the production level, three storage level firms that carry corn and soybeans, and a processor that operates corn and soybean processing plants. This representation of the number of firms in the grain supply chain reflects the market structure of the grain industry in which the amount of concentration increases from the production level to the processing level. That is, there are more firms at the production level relative to the storage level and more firms at the storage level relative to the processing level. The components of the fuzzy linear programming problems are operationalized with indices, decision variables, and parameters and the algebraic representations of the programming problem are formulated in the proceeding sub-sections.

Indices

t : Time index ($(t = 1,2,3)$ for three time horizons,

i : Production firm index $(i = 1,2,...,10)$ for ten production level firms,

j : Storage firm index $(j = 1, 2,3)$ for three storage level firms,

k : Processing facility type index $(k = 1,2)$ for corn and soybean processing plants,

n : Commodity type index $(n = 1,2)$ for corn and soybean,

m : Processed component part index $(m = 1,2,...,7)$ where $1,2,3,4$ are for ethanol, corn gluten meal, corn gluten feed, and corn oil from processed from corn while $5,6,7$ are for soybean meal soybean oil, and soybean hulls from processed soybean,

r : Input cash cost index $r = (1,2,3,4)$ for seed, soil fertility, chemicals, and hired labor,

Decision Variables

GX_{ni} : Amount of commodity type n produced by production firm i,

PI_{nit} : Amount of inventory of commodity type n for production firm i in time t,

X_{nijt} : Amount of commodity type n sold by production firm i to storage firm j in time t,

SI_{njt} : Amount of inventory of commodity type n for storage firm j in time t,

Q_{njt} : Amount of commodity type n sold by storage firm in time t,

Y_{mk} : Amount of component part m produced by processing plant k,

BC_i : Amount of borrowed capital required by production firm i

Parameters

Pc_{ni} : Per unit production cost of commodity type n for production firm i,

p^I_{nit} : Per unit market selling price for commodity type n for all production firms in time t,

α_i : Interest rate on borrowed capital for all production firms,

Sc_{nit} : Per unit storage cost of commodity type n for production firm i in time t ,
A_{ni} : An acre of land for commodity type n for production firm i ,
L_{rni} : Technological coefficients of input type r for commodity type n for firm i ,
b_i : Total available land for production firm i ,
ϕ_{ni} : Yield per acre for commodity type n for production firm i ,
N_{ni} : Maximum amount of commodity type n that can be sold by production firm i ,
p^J_{njt} : Per unit market price of commodity type n for storage firms in time t ,
Hc_{njt} : Per unit storage cost of commodity type n for storage firm j in time t ,
$Pcap_i$: Fixed storage capacity for production firm i ,
$Scap_j$: Fixed storage capacity for storage firm j ,
τ : Throughput multiplier for storage firms,
p_m : Per unit market price of component part m ,
Vc_{nk} : Per unit variable cost for processing commodity type n for processing plant k ,
β_{mn} : Per unit yield of component part m from commodity type n ,
M_{mk} : Maximum amount of component part m that can be sold by processing plant k ,
Cap_k : Processing capacity of plant type k ,
Tc_{nijt} : Per unit transaction cost for commodity type n between storage firm j and production firm i in time t ,
Tc_{njkt} : Per unit transaction cost for commodity type n between plant k and storage firm j in time t ,
Gc_{nijt} : Per unit product quality for commodity type n between storage firm j and production firm i in time t ,
Gc_{njkt} : Per unit product quality cost for commodity type n between plant k and storage firm j in time t ,
Rc_{nijt} : Per unit supply reliability cost for commodity type n between storage firm j and production firm i in time t ,
Rc_{njkt} : Per unit supply reliability cost for commodity type n between plant k and storage firm j in time t ,

a) Production Level Problem

The production level firms maximize profits from producing corn and soybeans, which can be sold in the first period or carried in inventory over the planning horizon. Borrowed capital is incorporated in the modeling for appropriate specification of the problems but the levels of borrowed capital are not reported in the results. The set of production level profit maximization problems is defined as follows:

$$\underbrace{Max}_{GX_{ni}, X_{nijt}, PI_{nit}, BC_i} \quad Z_i = \sum_{n=1}^{N} \left\{ \sum_{t=1}^{T} \left[\left((\omega_{nit}^{I} + P_{nit}^{I}) \bullet X_{nijt} \right) - \left(Sc_{nit} \bullet PI_{nit} \right) \right] - \left[\left(Pc_{ni} \bullet GX_{ni} \right) - \left(\alpha_{ni} \bullet BC_{ni} \right) \right] \right\}$$

$$\forall \ i = 1,2,...,10$$

(9)

Subject to

$$\sum_{n=1}^{N} A_{ni} \bullet GX_{ni} \qquad \le b_i \ \forall i \qquad (10)$$

$$\sum_{n=1}^{N} \left[\left(L_{nir} \bullet GX_{ni} \right) - BC_{ni} \right] \qquad \le \ 0 \ \ \forall i \ and \ r \qquad (11)$$

$$- \ \phi_{ni} \bullet GX_{ni} + X_{nij1} + PI_{ni1} \qquad \le 0 \ \ \forall n,i, \ j \, and \ t = 1 \qquad (12)$$

$$X_{nij2} - PI_{ni1} + PI_{ni2} \qquad \le 0 \ \ \forall n,i,j \ and \ t = 1,2 \qquad (13)$$

$$X_{nij3} \qquad - PI_{ni2} + PI_{ni3} \qquad \le 0 \ \ \forall n,i,j \ \ and \ t = 2,3 \qquad (14)$$

$$\sum_{t=1}^{T} X_{nijt} \qquad \le N_{ni} \ \ \forall \ n,i, \ and \ j \qquad (15)$$

$$\sum_{n=1}^{N} PI_{nit} \qquad \le Pcap_i \ \ \forall i \ and \ t \qquad (16)$$

$$GX_{ni}, X_{nijt}, PI_{nit}, BC_i \qquad \ge 0 \quad \forall i,n \ and \ t \qquad (17)$$

Equation 9 defines the objective functions for the production level firms. It is defined as the revenue from sales net the sum of production, borrowed capital, and inventory holding costs for each production level firm. Equation 10 is the land constraint, which restricts the amount produced from exceeding amount of available land. Equation 11 is the operating capital constraint. It is assumed that each producer has zero initial operating capital and can borrow as much capital as needed at a 10% interest rate. Equations 12 to 14 are the inventory accumulation constraints per production firm over the planning horizon. Equation 15 is the sales constraint, which restricts the amount sold from exceeding the amount produced by each per production firm. Equation 16 is the inventory capacity constraint per production firm and equation 17 is the production level non-negativity constraints.

b) Storage Level Problem

Each of the storage level firms maximizes profits from buying corn and soybeans from producers, which can be held in inventory and sold to processor over the planning horizon. The set of storage level profit maximization problems is specified as follows:

$$\underbrace{Maximize}_{X_{nijt},,Q_{njt},SI_{njt}} \; Z^J = \sum_{t=1}^{T}\sum_{n=1}^{N}\left\{\left[\left(p_{njt}^{J} \bullet Q_{njkt}\right)-\left(Hc_{njt} \bullet SI_{njt}\right)\right]-\sum_{i=1}^{I}\left(P_{nit}^{I} \bullet X_{nijt}\right) \quad \forall\, j=1,2,3 \right\} \qquad (18)$$

Subject to

$$Q_{njk1} - \sum_{i=1}^{I} X_{nij1} + SI_{nj1} = 0 \quad \forall n, j, k,\ and\ t=1 \qquad (19)$$

$$Q_{njk2} - \sum_{i=1}^{I} X_{nij2} - SI_{nj1} + SI_{nj2} = 0 \quad \forall n, j, k,\ and\ t=1,2 \qquad (20)$$

$$Q_{njk3} - \sum_{i=1}^{I} X_{nij3} - SI_{nj2} + SI_{nj3} = 0 \quad \forall n, j, k\ and\ t=2,3 \qquad (21)$$

$$\sum_{t=1}^{T} Q_{njkt} \leq \tau Scap_j \quad \forall\ n, j\ and\ k \qquad (22)$$

$$\sum_{i=1}^{T} X_{nijt} \leq N_{ni} \quad \forall n, i\ and\ j \qquad (23)$$

$$\sum_{t=1}^{T}\sum_{i=1}^{I} X_{nijt} \leq \tau Fcap_j \quad \forall n\ and\ j \qquad (24)$$

$$\sum_{n=1}^{N} SI_{njt} \leq Fcap_j \quad \forall j\ and\ t \qquad (25)$$

$$Q_{njt},\ X_{nijt},\ SI_{njt} \qquad \geq 0 \qquad \forall n, i, j, \text{ and } t \qquad (26)$$

Equation 18 defines the objective functions for the storage level firms. It is defined as revenue from sales net the sum of the costs of buying corn and soybeans and for holding inventory over the planning horizon. Equations 19 to 21 are the inventory accumulation constraints per period. Equation 22 is availability constraint that restricts total amount purchased from each production source from exceeding amount available for sale in each period. Equation 23 is the requirement constraint that restricts the total amount purchased over the planning horizon from exceeding total annual throughput for each storage firm. Equation 24 is the total supply constraint by each producer over the planning horizon. Equation 25 is the storage capacity constraint, and equation 26 is the storage level non-negativity constraint.

c) Processing Level Problem

The processing level firm maximizes its profits by buying corn and soybeans over the planning horizon from storage level firms and processing them into component products, which are sold. The profit maximization problem of the joint corn-soybean processing plants is defined as follows:

$$\underbrace{Maximize}_{Y_{mk},Q_{njkt}} \ Z^K = \sum_{m=1}^{M}\left(p_m^{PR} \bullet \sum_{k=1}^{K} Y_{mk}\right) - \sum_{n=1}^{N}\left[\left(\sum_{j=1}^{J}\sum_{t=1}^{T} Q_{njkt}\right) \bullet \sum_{k=1}^{K} VC_{nk}\right] - \sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{t=1}^{T}\left(P_{njt}^{J} \bullet \sum_{j=1}^{J} Q_{njkt}\right) \qquad (27)$$

Subject to

$$Y_{mk} - \beta_{mn} \bullet \sum_{t=1}^{T}\sum_{j=1}^{J} Q_{njkt} \qquad \leq 0 \qquad \forall m, n, \text{ and } k \qquad (28)$$

$$Y_{mk} \qquad \leq M_{mk} \qquad \forall m \text{ and } k \qquad (29)$$

$$\sum_{t=1}^{T} Q_{njkt} \qquad \leq \tau Scap_j \qquad \forall n, j \text{ and } k \tag{30}$$

$$\sum_{t=1}^{T}\sum_{j=1}^{J} Q_{njkt} \qquad = Cap_k \qquad \forall n \text{ and } k \tag{31}$$

$$Y_{mk}, Q_{njkt} \qquad \geq 0 \qquad \forall n, j, m, k, t \tag{32}$$

Equation 27 is the objective function for the processing level problem. It is defined as the revenue from sales of processed products net the sum of the costs of purchasing corn and soybeans and variable processing costs. Equation 28 is the product balance constraint, equation 29 is sales constraint per component part, equation 30 is the supply constraint per storage level firm, equation 31 is the demand constraint per processing plant, and equation 32 is the processing level non-negativity constraint.

d) Channel Coordinator's Problem

The channel coordinator's objective is to minimize costs related to product quality assurance, supply reliability, and transactions across the supply chain. The channel coordinator's problem is defined as follows:

$$\underbrace{Minimize}_{X_{nijt}, Qnjt} \; Z^T = \sum_{n=1}^{N}\sum_{i=1}^{I}\sum_{t=1}^{T}\left(Tc_{nijt} * X_{nijt}\right) + \sum_{n=1}^{N}\sum_{J=1}^{J}\sum_{t=1}^{T}\left(Tc_{njkt} * Q_{njkt}\right) \tag{33}$$

$$\underbrace{Minimize}_{X_{nijt}, Qnjt} \; Z^G = \sum_{n=1}^{N}\sum_{i=1}^{I}\sum_{t=1}^{T}\left(Gc_{nijt} * X_{nijt}\right) + \sum_{n=1}^{N}\sum_{J=1}^{J}\sum_{t=1}^{T}\left(Gc_{njkt} * Q_{njkt}\right) \tag{34}$$

$$\underbrace{Minimize}_{X_{nijt}, Qnjt} \; Z^R = \sum_{n=1}^{N}\sum_{i=1}^{I}\sum_{t=1}^{T}\left(Rc_{nijt} * X_{nijt}\right) + \sum_{n=1}^{N}\sum_{J=1}^{J}\sum_{t=1}^{T}\left(Rc_{njkt} * Q_{njkt}\right) \tag{35}$$

Subject to

$$\begin{array}{ll} PRODUCTION\ \ LEVEL\ \ CONSTRAINTS & (9-17) \\ STORAGE\ \ LEVEL\ \ CONSTRAINTS & (18-26) \\ PROCESSING\ \ LEVEL\ \ CONSTRAINTS & (27-32) \end{array} \quad (36)$$

$$X_{nijt}, Q_{njkt} \qquad \geq 0 \quad \forall n, i, j, t \quad (37)$$

Equations 33, 34, and 35 are the transaction, product quality, and supply reliability costs minimization objective functions, which are defined as the sum of transaction costs, product quality costs, and supply reliability costs between producers and storage level firms and between the storage and processing level firms. The channel coordinator's objectives are constrained by the production, storage, and processing level constraints defined in equation 36. Finally, the non-negativity constraints are defined in equation 37.

4. Data Sources and Model Parameterization

The fuzzy linear programming application in this study does not require pinpoint accuracy in model parameterization because of the limitation of detailed and comprehensive data. Using representative data from the Illinois grain industry allows us to incorporate existing data. The sources of the data that is used to parameterize the production, storage, and processing level problems are discussed in the proceeding paragraphs.

The production level data is based on 2002 farm business records for Illinois farms involved in joint corn-soybean production (Farm Business Farm Management, 2002). A sample of ten firms is selected from all regions and from all firm sizes to represent the cost structure of joint corn-soybeans operations in the state of Illinois, one fore each decile of farm size. The on-farm storage costs are adjusted to reflect the opportunity costs of carrying inventory over the planning horizon because carrying inventory and delaying loan repayment is an accruing cost.

The sales prices are based on average corn and soybeans prices received by Illinois farmers (Illinois Agricultural Statistics, 2002).

Storage level data is based on the operating costs of Topflight, Assumption, and Grand Prairie elevator cooperatives in Illinois. The companies carry corn and soybeans and operate multiple facilities in different locations. The multiple storage facilities of each cooperative adopt the same policies in terms of storage rates, delivery, product quality, and so forth, as stipulated by their head office. Hence, a sample of three facilities is representative of a large number of operations in the state. It is assumed that differences in their storage rates per bushel are reflections of their cost structures. The storage rates per bushel were also adjusted for the opportunity cost of carrying inventory over the planning horizon. Following consultation with industry experts, the annual throughput multiplier was fixed at 1.5 times of each storage firm's fixed storage capacity.

The processing level data are based on estimates that reflect U.S. averages because the cost structures for corn and soybeans plants are capital intensive, and competition is national rather than local, unlike competition in the production and storage levels. The per unit variable costs for the soybean processing plant are based on 1995 U.S. estimates in the Practical Handbook of Soybean Processing and Utilization (Fiala, 1995, p. 519-535). The per bushel soybean component (soybean meal, soybean oil and soybean hulls) yield and per unit sales price are based on the average annual values in Oil Crop Situation and Outlook Yearbook (ERS/USDA, 2002). Estimates on corn processing is based on a wet corn milling process, which is the dominant ethanol production process in Illinois. The cost and price of the processed components (ethanol, corn gluten feed, corn gluten meal, and corn oil) are based on estimates from the Iowa Ethanol Plant Feasibility Study (Brian and Brian, Inc. 2000). The component yield from the wet corn-milling process is collected from Soya and Oilseed Bluebook (Soya and Oilseed Bluebook, 2002).

Data for the channel coordinator's problems is based on estimates of direct and hidden costs in identity preserved supply chains for Missouri and Illinois grain elevators (Maltsbarger and Kalaitzandonakes, 2000). A number of assumptions are made in order to appropriately apply the data to the present study. First, the costs are based on interaction between storage firms and producers. We assume similar per unit costs between storage firms and the processor. Secondly, the costs are based on an identity preserved corn supply chain. We assume similar per unit costs for commodity corn and soybeans. Finally, the sizes of grain elevators modeled are different from the ones considered in this study. We use ranges to capture the sizes analyzed in this study.

5. Discussion of Results

The models constructed in section Three are analyzed for a small grain supply chain that has a total commodity flow capacity of one million bushels of corn and three hundred and seventy-five thousand bushels of soybeans. The channel size in terms of number of firms and flow capacity is arbitrary and can be extended to grain supply chains of any size. The membership functions are aggregated using the "fuzzy and" operator. The operator is limited in that it is difficult to identify an optimal compensation rate because the compensation rate monotonically increases with degree of compensation (Canz, 1996). That is as the compensation rate increases from zero to one, the amount of compensation increases. In this study we assume an average compensation rate of 0.50, which is the mid point of the range $0 \leq \gamma \leq 1$ explained in Equation 4.

The procedure to calculate the optimal weights was described in equations 5 to 8. Because the analyses adopt the fuzzy linear programming approach in which uncertainty is incorporated in the objective functions, the coefficient of variation (CV) is used to incorporate uncertainty in the weights of the channel coordinator's objectives. This is because CV is a good measure of the relative variability within a system, and it is expressed mathematically as $CV_s = \sigma_s / \mu_s$ where σ *and* μ are the standard deviations and means per unit of the transaction, product quality, and supply reliability costs. Since the estimated CV are on a per unit (bushels) basis while the ideal solutions are total dollar estimates, we multiply the per unit CV by the total flow capacities to define spreads around the ideal solutions. The ranges of the spreads (differences between upper and lower bounds) are then used to implement the Eigenvector method described in equations (5-8).

The optimal weights from the system of equations in (8) are estimated using a mathematics solver (Mathematica). The calculated optimal weights are 0.195 for transaction cost, 0.224 for product quality cost, and 0.581 for supply reliability cost. The detailed results of the two analyses are reported in Tables 2 and 3 in the Appendix. A comparison of the two analyses in terms of global achievement levels, firm level profits, total supply chain profits, channel coordinator's costs, and net supply chain profits is summarized in Table 1. The discussions in the proceeding paragraphs are based on the summarized results.

Table 1. Comparison of Supply Chain Performance Using Equal and Optimal Weights for the Coordinator's Goals

	Equal Weights	Optimal Weights
Global Satisfaction Levels (λ)	0.67	0.70
Supply Chain Activities		
Production	940,049.2	995,601.2
Storage	431,131.7	433,134.7
Processing	1,459,705.9	1,456,195.8
Total Profits	2,830,886.8	2,884,931.7
Channel Designer's Costs		
a) Quality cost	104,768.10	103,090.9
b) Supply reliability cost	424,178.2	432,,673..3
c) Transaction cost	88,768.1	87,217.6
Total Cost	617,643.6	622,981.8
Net Supply Chain Profit	2,213,243.2	2,261,949.9

The overall satisfaction in the compromise solution increased from 0.67 in the analysis in the analysis with equal weights to 0.70 in the analysis with optimal weights. Regarding the channel coordinator's costs, the total costs increased slightly from $617,502.70 in the analysis with equal weights to $622,981.8 in the analysis with optimal weights, representing a saving of only $5,338.20 to the channel coordinator. The supply reliability costs increased by $8,495.10 while transaction and product quality costs dropped by $1,550.50 and $1,606.40 when comparing the solution with equal weights to the analysis with optimal weights.

While the overall cost saving to the channel coordinator is minimal, prioritizing its goals enhanced the total production level and total storage level profits by $ 55,552.10 and $2,003.00. The processing level profit on the other hand decreased by $3,510.10. The total supply chain profit also increased by $54,044.90 and a net supply chain profit of $48,706.70. This represents an average gain to firms in the supply chain of about $3,479.0.

6. Conclusion

This study analyzes the optimal decisions of a decentralized controlled multi-objective grain supply chain problem in which the firm level profit maximization objectives are conflicting with the channel coordinator's cost minimization objectives. Considering that the channel coordinator's objectives may not equal impact the performance of the grain supply chain, a linear weighting method is used to determine optimal weights that reflect the relative importance of the channel coordinator's goals. Two analyses were conducted to determine whether prioritizing the channel coordinator's goals enhance the overall performance of the grain supply chain. The first analysis models the supply chain problem with equally weighted channel coordinator's goals while the second analysis used the estimated optimal weights.

The main finding of the study is that prioritizing the channel coordinator's objectives enhances the overall all supply chain performance of the grain supply chain in term of global satisfaction of their compromise solutions, total supply chain profits, channel coordinator's costs, net supply chain profits, production and storage level profits. However the processor did not benefit but not be a significant amount.

Two important questions that have implications on the findings are the following: First, "Why should the processor who is the dominant player of the system be inclined to hire a channel coordinator to manage the supply chain costs if prioritizing the channel coordinator's goals enhanced the production and storage level profits and other global performance measures but at a cost to the processor?" A supply chain's competitiveness is not measured by how well the dominant firm outperforms the other firms of the supply chain. Rather, it is measured by how well the supply chain as a whole performs relative to a competitor's supply chain. Long-run commitment of the production and storage level firms to a processor's supply chain is contingent upon the satisfaction they derived on the overall supply chain outcome.

Secondly, does the net gain $48,706.70 to the supply chain profits justify hiring a channel coordinator to mange the supply chain? According to Illinois Labor statistics (2002), the average annual salary of a logistics manager is about $72,189.00, which is significantly higher than the net gain in performing the channel coordinator's functions. However, the size of the supply chain considered in this study is relatively small compared to the flow capacities of major grain supply chains in the State of Illinois. For example firms such as ADM, Cargill, Bunge etc., which operate major supply chains in the state of Illinois have annual flow capacities of tenths of millions of bushels. Scaling the present study to the size of practical operations may result in significant gains to the supply chain that may justify hiring a logistics manager.

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APPENDIX

Table 2. Compromise Solution for Grain Supply Chain Problem Analyzed Using Equal Weights for the Channel Coordinator's Goals

SUPPLY CHAIN FIRMS AND ACTIVITIES		GL0BAL SATISFACTION LEVEL $\lambda = 0.67$				PROFIT/COST (Dollars)
		DECISION VARIABLES				
PRODUCTION LEVEL FIRMS		PROPORTION OF LAND (Acres)	COMMODITY FLOW & INVENTORY PER PERIOD (bushels)			
			PERIOD1	PERIOD2	PERIOD3	
	CORN	300.0	0	46,800.0	0	
FIRM1			(46,800.0)	0	0	
	SOYBEAN	463.7	22,257.5	0	0	51,303.6
			0	0	0	
	CORN	390.1	37,403.0	24,228.0	0	
FIRM2			(24,228.0)	0	0	
	SOYBEAN	858.9	0	6,344.4	34,884.3	46,103.1
			(41,228.7)	(34,884.3)	0	
	CORN	626.7	33,625.0	0	71,028.0	
FIRM3			(71,028.0)	(71,028.0)	0	
	SOYBEAN	823.3	12,626.0	28,539.9	0	93,606.1
			(28,539.9)	0	0	
	CORN	940.8	0	36,442.0	121,614.0	
FIRM4			(158,056.0)	(121,614.0)	0	
	SOYBEAN	922.2	0	27,097.0	17,012.0	91,500.0
			(46,109.0)	(17,012.0)	0	
	CORN	319.0	44,342.0	5,420.6	0	
FIRM5			(5,420.0)	0	0	
	SOYBEAN	356.0	17,444.6	0	0	41,792.1
			0	0	0	
	CORN	517.9	0	79,752.0	0	
FIRM6			(79,752.0)	0	0	
	SOYBEAN	42.0	0	2,058.9	0	55,082.6
			(2,058.9)	0	0	
	CORN	501.8	77,272.0	0	0	
FIRM7			0	0	0	
	SOYBEAN	710.2	23,191.0	9,479.8	0	104,107.5
			(9,479.8)	0	0	
	CORN	445.0	70,310.0	0	0	
FIRM8			0	0	0	
	SOYBEAN	695.0	1,323.5	0	32,036.5	41,352.4
			0	0	0	
	CORN	1312.0	70,381.3	136,910.7	0	
FIRM9			(136,910.7)	0	0	
	SOYBEAN	1277.0	10,998.7	49,021.3	0	180,734.5
			(49,021.3)	0	0	
	CORN	870.3	0	32,105.3	110,366.7	
FIRM10			(144,472.0)	(110,366.7)	0	
	SOYBEAN	1052.6	36,669.2	0	16,984.8	234,467.3
			0	(16,984.8)	0	
STORAGE LEVEL FIRMS						
	CORN		71,028	40,703.3	101,352.7	
FIRM1			0	(30,324.7)	0	
	SOYBEAN		34,884.3	19,135.2	50,633.4	110,237.2
			0	(15,749.1)	0	
	CORN		121,614.0	121,614.0	121,614.0	
FIRM2			0	0	0	
	SOYBEAN		32,761.1	48,510.1	17,012.0	117,245.9
			0	0	0	
	CORN		140,691.3	171,016.0	110,366.7	
FIRM3			0	0	0	
	SOYBEAN		49,021.3	49,021.3	49,021.3	203,648.6
			0	0	0	
PROCESSING LEVEL FIRM						
PROCESSED PRODUCTS		PROCESSED PRODUCTS (Litters 'a' and Pounds for 'b to g')				
a) Ethanol				26,000,000.0		
b) Corn gluten meal				3,000,000.0		1,459,705.9
c) Corn gluten feed				12,500,000.0		
d) Corn Oil				1,500,000.0		
e) Soybean meal				18,000,000.0		
f) Soybean oil				4,125,000.0		
g) Soybean Hull				375,000.0		
TOTAL SUPPLY CHAIN PROFIT						**2,830,886.8**
Transaction Cost						88,768.1
Product Quality Cost						104,697.3
Supply Reliability Cost						424,178.2
TOTAL SUPPLY CHAIN COST						**617,502.7**

* Inventory values are in brackets '( )'

Table 3. Compromise Solution for the Grain Supply Chain Problem Analyzed Using Optimal Weights for the Channel Coordinator's Coals

SUPPLY CHAIN FIRMS AND ACTIVITIES		GL0BAL SATISFACTION LEVEL $\lambda = \mathbf{0.70}$				PROFIT/COST (Dollars)
		DECISION VARIABLES				
PRODUCTION LEVEL FIRMS		PROPORTION OF LAND (Acres)	COMMODITY FLOW & INVENTORY PER PERIOD (bushels)			
			PERIOD1	PERIOD2	PERIOD3	
	CORN	300.0	9,397.0	0	37,403.0	
FIRM1			(37,403.0)	(37,403.0)	0	
	SOYBEAN	498.1	0	0	23,909.4	51,303.6
			(23,909.4)	(23,909.4)	0	
	CORN	390.10	61,631.0	0	0	
FIRM2			0	0	0	
	SOYBEAN	858.9	0	35,625.2	5,603.5	46,103.1
			(41,228.7)	(5,603.5)	0	
	CORN	626.7	0	71,028.0	33,625.0	
FIRM3			(104,653.0)	(33,625.0)	0	
	SOYBEAN	823.3	35,625.2	0	5,541.6	93,606.1
			(5,541.6)	(5,541.6)	0	
	CORN	723.9	121,614.0	0	0	
FIRM4			0	0	0	
	SOYBEAN	922.2	40,635.0	5,917.8	0	90,876.4
			(5,917.8)	0	0	
	CORN	319.0	0	0	49,762.0	
FIRM5			(49,762.0)	(49,762.0)	0	
	SOYBEAN	356.0	0	17,444.6	0	60,513.4
			(17,444.6)	0	0	
	CORN	517.9	0	44,342.0	35,409.4	
FIRM6			(79,751.9)	(35,409.4)	0	
	SOYBEAN	524.1	0	17,993.2	7,689.2	90,133.2
			(25,682.4)	(7,689.2)	0	
	CORN	501.8	0	77,272.0	0	
FIRM7			(77,272.0)	0	0	
	SOYBEAN	710.2	0	0	32,670.8	104,107.5
			(32,670.8)	(32,670.8)	0	
	CORN	445.0	0	70,310.0	0	
FIRM8			(70,310.0)	0	0	
	SOYBEAN	695.0	32,360.0	0	0	41,352.4
			0	0	0	
	CORN	1312.0	0	36,276.0	171,016.0	
FIRM9			(207,292.0)	(171,016.0)	0	
	SOYBEAN	1277.0	15,661.0	44,358.7	0	180,734.5
			(44,358.7)	0	0	
	CORN	1418.3	171,016.0	64,430.0	0	
FIRM10			(64,430.0)	0	0	
	SOYBEAN	1047.6	0	4,662.7	44,021.3	228,467.3
			(53,684.0)	(44,021.3)	0	
STORAGE LEVEL FIRMS						
	CORN		40,703.3	101,352.7	16,028.0	
FIRM1			(30,324.7)	0	(54,531.9)	
	SOYBEAN		35,625.2	35,625.2	30,324.7	107,347.8
			0	0	0	
	CORN		121,614	60,964.8	91,289.3	
FIRM2			0	(60,649.3)	0	
	SOYBEAN		40,353.5	40,353.5	40,924.2	131,235.7
			(282.1)	(564.3)	0	
	CORN		171,016.0	171,016.0	131,016.0	
FIRM3			0	0	0	
	SOYBEAN		49,021.3	49,021.3	49,021.3	194,551.2
			0	0	0	
PROCESSING LEVEL FIRM						
		PROCESSED PRODUCTS (Litters 'a' and Pounds for 'b to g')				
a) Ethanol		26,000,000.0				
b) Corn gluten meal		3,000,000.0				
c) Corn gluten feed		12,500,000.0				
d) Corn Oil		1,500,000.0				1,456,195.8
e) Soybean meal		18,000,000.0				
f) Soybean oil		4,125,000.0				
g) Soybean Hull		375,000.0				
TOTAL SUPPLY CHAIN PROFIT						**2,848,127.0**
Transaction cost						87,217.6
Quality cost						103,090.9
Supply reliability Cost						432,673.3
TOTAL SUPPLY CHAIN COST						**622,981.8**

* Inventory values are in brackets '( )'

SHORT SUMMARY

A fuzzy multi-objective programming model is used to analyze the optimal decisions in a multi-objective grain supply chain in which the firm-level firm goals are conflicting with the channel coordinator's goals. The relative impact of the channel coordinator's goals on performance of the supply chain is determined through a linear weighting method. The study finds that prioritizing the channel coordinator's goals enhances the overall performance of the system.