Comparative Evaluation of the Performance of Spans of Control Designs in Grain Supply Chains

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Abstract

The structure of U.S. grain systems is transforming into vertically coordinated systems. Agribusiness firms are adopting various forms of organizational structures to coordinate the activities of firms that operate in the different levels of the systems. Three spans of control grain supply chain are modeled, analyzed, and their performances compared. The designs differ in terms of degree of concentration of asset ownership and the extent to which decision-making is controlled across the designs. Fuzzy multi-objective linear programming is used to analyze the spans of control designs. The performances of the spans of control designs are compared in terms of total firm level profits, total supply chain profits, and the overall satisfaction level associated with the compromise solutions of the systems. The main conclusion of the study is that under cooperative relationships, the grain supply chain performance (in all measures) increases with amount of control.

Key words: Grain supply chain, Spans of Control Designs, Fuzzy Multi-objective Linear Programming, and Supply Chain Performance Measures

Introduction

The structure of the U.S. grain and oil seed systems are transforming from independent production, storage, and processing sub-systems into systems whose internal organizational structures are vertically coordinated. Agribusiness firms are adopting various forms of organizational designs to coordinate the activities of their systems. Effective supply chain design was been identified as a key determinant for competitiveness in most industries (Rangan, Zoltners, and Becker, 1986). This underscores the need to evaluate the relative effectiveness or performances of the organizational structures that are adopted in the grain industry. It has been proposed in the agricultural economics literature that the performance of vertical coordination alternatives could be evaluated in terms of income distribution (Barry, 1995), equity in income distribution (Henderson, 1979), and income and risk distribution (Rhodes, 1995).

Poray, Gray, Boehlje, and Preckel (2003) used a sequential stochastic optimization model to evaluate the impact of information flow, product characteristics, and financial flows on the performances (measured in terms of risk and income distribution) of governance structures (spot market, market contracts, and vertical integration) in a producer-packer pork supply chain. The study found that the choice of coordination mechanism does not dramatically alter total system performance. However coordination mechanisms differ in risk distributions and returns to producers and packers. Secondly, there are economic and financial benefits for both producers and packers to reorganize from spot market to contract or vertical integration coordination systems. Finally, there is no payment range over which producers and packers could negotiate to move from contract system to vertical integration system.

Poray et al., like others that analyzed the pork supply chain (Cozzarin, 1996; Cloutier, 1999), is limited in that it modeled a supply chain that consists of only two decision-makers (firms) and two-levels. While such a simplistic supply chain structure is convenient for applications using the analytical methods adopted, they have limited applicability to most supply chains that consist of multiple decision-makers and may have more than two levels.

This study models supply chains that are based on functional organizational structures that are observed in the grain industry. Three supply chain designs characterized as 1) decentralized, 2) consolidated storage, and 3) integrated storage-processing, and are described in the next section. They are operationally referred to in this study as grain supply chain spans of control designs because the amount of control exercised in the supply chains increases from the decentralized to the integrated design.

Furthermore, this study adopts fuzzy multi-objective linear programming technique to analyze the designs for the following reasons. First, the procedure is capable of modeling a system that consists of many decision-makers (firms) and multiple levels. 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 account for uncertainties in the supply chain environment and that the optimal tradeoff decisions distribute 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 specific objective of this study is to model, analyze, and compare the performances of spans of control designs in a tri-level, multi-firm, and multi-period grain supply chain. The performances of the spans of control designs are compared in terms of total firm level profits, total supply chain profits, and the overall satisfaction level in compromise solutions for each of span of control design. The rest of the paper is organized as follows. Section two describes the structures of the chain spans of control designs. Section three presents the theoretical framework on fuzzy multi-objective linear programming. Section four describes the characteristics of grain supply chain problems and presents mathematical formulations of the spans of control design problems. Section five discusses the sources of data and model parameterization. Section six discusses the results and the final section provides conclusions of the study.

2. Description of the Grain Supply Chain Spans of Control Designs

Two practical examples of the structures of grain supply chain spans of control designs are drawn from the $LoSatSoy^{M}$ Oil and General Mills' Wheaties supply chains (King, 2002). The $LoSatSoy^{M}$ Oil supply chain is coordinated by contracts, which pay participating production and storage level firms a premium above the local per bushel price for soybeans. All the contracted elevators are required to ship the low saturated soybeans to an identity preserved soybeans processing plant. This supply chain design is conceived as a decentralized controlled system in which the production, storage, and processing level firms are separately owned and their operational decisions are independent. In the case of the General Mills supply chain, the elevators owned by General Mills in Idaho contract with farmers to produce identity preserved wheat and the participating farmers are paid premiums per bushel of wheat. The wheat is shipped from General Mills' elevators to its processing plant. This design is conceived as an integrated storage-processing design because the assets are owned and the operational decisions of the storage and processing levels are controlled by General Mills.

A third grain supply chain design is conceived as one in which the storage level is consolidated or horizontally integrated. In this case we are considering an organizational structure similar to that of grain elevator cooperatives, which operate multiple facilities in different geographical locations. Thus, information flows horizontally from the head offices to the facilities. It should be apparent from the three structures the amount of control in terms of asset ownership and concentration of decision-making increased from the decentralized design to the consolidated design and then to the integrated design.

3. Theoretical Framework

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

$$\begin{aligned}
&\text{Production Level Objectives} \\
&\textit{Maximize } (\tilde{Z}x)_i = \left[(\tilde{Z}x)_1, (\tilde{Z}x)_2, ..., (\tilde{Z}x)_I\right]^T \\
&\text{Storage Level Objectives} \\
&\textit{Maximize } (\tilde{Z}x)_j = \left[(\tilde{Z}x)_1, (\tilde{Z}x)_2, ..., (\tilde{Z}x)_J\right]^T \\
&\text{Processing Level Objectives} \\
&\textit{Maximize } (\tilde{Z}x)_k = \sum_{k=1}^{K}\left[(\tilde{Z}x)_1 + (\tilde{Z}x)_2 +, ..., +(\tilde{Z}x)_K\right]^T \qquad (1) \\
&\textit{Subject to} \\
&x \in X = \left\{x_{i,j,k} \,\middle|\, (Ax)_i + (Ax)_j + (Ax)_k (\circ) B_{i,j,k}, x_{i,j,k} \leq 0\right\}
\end{aligned}$$

Where $(x_{i,j,k})$ is an n dimensional vectors of decision variables, $(\sim)$ represents fuzzy objective functions, $(\circ)$ is an operator that can take either $(\leq, =, \geq)$ signs in the constraints, $x \in X$ represent the complete set of crisp supply chain constraints, $B_{i,j,k}$ are m dimensional constant vectors for available resources, and $(Ax)_{i,j,k}$ 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. While the shape of the membership functional forms can be either linear or non-linear, in this study like in most fuzzy linear programming applications the linear membership functional form is applied because of its computational simplicity. Ideally, the objective membership function should be constructed interactively with experts of the systems or experienced decision-makers, which could not be done in this study. Following (Zimmermann, 1978) the upper bounds or ideal solutions $(Z^*_{i,j,k})$ and lower bounds or anti-ideal solutions $(Z^-_{i,j,k})$ of the tolerance intervals are used to construct the objective membership functions. They are estimated by solving the following problems:

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

The objective membership functions $\mu(Zx)_{i,j,k}$ expressing degree of individual optimalities for the sub-problems are mathematically expressed as follows:

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

The fuzzy multi-objective linear programming problem in (1) is transformed into a standard linear programming problem following (Zimmermann, 1978). The transformation process involves first introducing an auxiliary variable (λ) and then applying the Bellman and Zadeh (1970) min-operator. The transformed linear programming problem is defined as follows

$$\begin{aligned} &Max\ \lambda \\ &Subject\ to \\ &x \in X \\ &\mu_i(Zx)_i = \tfrac{(Zx)_i - Z_i^-}{Z_i^* - Z_i^-} \ge \lambda_i \quad \forall i \\ &\mu_j(Zx)_j = \tfrac{(Zx)_j - Z_j^-}{Z_j^* - Z_j^-} \ge \lambda_j \quad \forall j \\ &\mu_k(Zx)_k = \tfrac{(Zx)_k - Z_k^-}{Z_k^* - Z_k^-} \ge \lambda_k \quad \forall k \\ &\lambda \in [0,1] \end{aligned} \tag{4}$$

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. Furthermore (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

$$
\begin{aligned}
& Max\ \mu_{and} = \lambda + (1-\gamma)\frac{1}{I+J+K}\left[\sum_{i=1}^{I}\lambda_i + \sum_{j=1}^{J}\lambda_j + \sum_{k=1}^{K}\lambda_k\right] \\
& Subject\ to \\
& x \in X \\
& \mu_i(Zx_i = \tfrac{(Zx)_i - Z_i^-}{Z_i^* - Z_i^-} \geq \lambda + \lambda_i \quad \forall i \\
& \mu_j(Zx)_j = \tfrac{(Zx)_j - Z_j^-}{Z_j^* - Z_j^-} \geq \lambda + \lambda_i \quad \forall j \\
& \mu_k(Zx)_k = \tfrac{(Zx)_k - Z_k^-}{Z_k^* - Z_k^-} \geq \lambda + \lambda_k \quad \forall k \\
& \lambda + \lambda_i \leq 1 \quad \forall i \\
& \lambda + \lambda_j \leq 1 \quad \forall j \\
& \lambda + \lambda_k \leq 1 \quad \forall k \\
& \lambda\ and\ \gamma \in [0,1]
\end{aligned}
\tag{5}
$$

Where γ is the degree of compensation defined within the interval ($0 \leq \gamma \leq 1$)

4. Mathematical Formulations of Spans of Control Design 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 temporal dimension in grain supply chain decision-making, the spans of control designs are modeled as multi-period problems 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 average prices of the systems.

A representative grain supply chain consisting of fourteen firms with ten production level firms that are involved in joint corn-soybeans production, three storage level firms that carry corn and soybeans, and a processor that operates corn and soybean processing plants are used to model the three spans of control designs. 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 stated above are operationalized with indices, decision variables, and parameters, which are formulated in proceeding sub-sections.

Indices

t : Time index ($(t = 1,2,3)$ for three periods in the planning 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 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,
ω^I_{nit} : Incentive per unit of commodity type n in time period t, paid to production level firms for participation in the supply chain,
ω^J_{njt} : Incentive per unit of commodity type n in time period t paid to storage level firms for participating in the supply chain,
Tc_{nijt} : Per unit transaction cost for commodity type n between storage firm j and production firm i in time t,
Tc_{njt} : Per unit transaction cost for commodity type n between plant k and storage firm j in time t,

We now turn to the construction of the fuzzy optimization problems for the three channel designs which are to be compared: decentralized, consolidated storage, and integrated storage-processing.

4.1. Decentralized Supply Chain Problem

The independent production, storage, and processing level problems of the decentralized design are formulated in the proceeding sub-sections.

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 problem is defined as follows:

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

$$\forall\ i = 1,2,...,10 \qquad (6)$$

Subject to

$$\sum_{n=1}^{N} A_{ni} \bullet GX_{ni} \leq b_i \ \forall i \qquad (7)$$

$$\sum_{n=1}^{N}\left[\left(L_{nir} \bullet GX_{ni}\right) - BC_{ni}\right] \leq 0 \ \ \forall i \ and \ r \qquad (8)$$

$$- \phi_{ni} \bullet GX_{ni} + X_{nij1} + PI_{ni1} \leq 0 \ \ \forall n,i,\ j\ and\ t = 1 \qquad (9)$$

$$X_{nij2} - PI_{ni1} + PI_{ni2} \leq 0 \ \ \forall n,i,j \ and \ t = 1,2 \qquad (10)$$

$$X_{nij3} - PI_{ni2} + PI_{ni3} \leq 0 \ \ \forall n,i,j \ and \ t = 2,3 \qquad (11)$$

$$\sum_{t=1}^{T} X_{nijt} \leq N_{ni} \ \ \forall\ n,i,\ and\ j \qquad (12)$$

$$\sum_{n=1}^{N} PI_{nit} \leq Pcap_i \ \ \forall i \ and \ t \qquad (13)$$

$$GX_{ni}, X_{nijt}, PI_{nit}, BC_i \geq 0 \ \ \forall i,n \ and \ t \qquad (14)$$

Equation 6 defines the objective functions for the production level firms. It defined as the revenue from sales net the sum of production, borrowed capital, and inventory holding costs for each of the production level firms. Equation 7 is the land constraint, which restricts the amount produced from exceeding amount of available land. Equation 8 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 9 to 11 are the inventory accumulation constraints per production firm over the planning horizon. Equation 12 is the sales constraint, which restricts the amount sold from exceeding the amount produced. Equation 13 is the inventory capacity constraint, and equation 14 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 at different periods over the planning horizon. The set of storage level profit maximization problems is specified as follows:

$$\underbrace{Maximize}_{X_{nijt},Q_{njt},SI_{njt}} Z^J = \sum_{t=1}^{T}\sum_{n=1}^{N}\left\{\begin{array}{c}\left[\left((\omega_{njt}^J + p_{njt}^J)\bullet Q_{njkt}\right)-\left(Hc_{njt}\bullet SI_{njt}\right)\right]-\sum_{i=1}^{I}\left((\omega_{nit}^I + P_{nit}^I)\bullet X_{nijt}\right) \\ -\sum_{i=1}^{I}\left(Tc_{nijt} * X_{nijt}\right) \qquad \forall\, j=1,2,3\end{array}\right\} \tag{15}$$

Subject to

$$Q_{njk1} - \sum_{i=1}^{I} X_{nij1} + SI_{nj1} = 0 \quad \forall n, j, k, \text{ and } t=1 \tag{16}$$

$$Q_{njk2} - \sum_{i=1}^{I} X_{nij2} - SI_{nj1} + SI_{nj2} = 0 \quad \forall n, j, k, \text{ and } t=1,2 \tag{17}$$

$$Q_{njk3} - \sum_{i=1}^{I} X_{nij3} - SI_{nj2} + SI_{nj3} = 0 \quad \forall n, j, k \text{ and } t=2,3 \tag{18}$$

$$\sum_{t=1}^{T} Q_{njkt} \leq \tau Scap_j \quad \forall\ n, j \ and\ k \tag{19}$$

$$\sum_{i=1}^{T} X_{nijt} \leq N_{ni} \quad \forall n, i \ and\ j \tag{20}$$

$$\sum_{t=1}^{T} \sum_{i=1}^{I} X_{nijt} \leq \tau Fcap_j \quad \forall n \ and\ j \tag{21}$$

$$\sum_{n=1}^{N} SI_{njt} \leq Fcap_j \quad \forall j \ and\ t \tag{22}$$

$$Q_{njt},\ X_{nijt},\ SI_{njt} \geq 0 \qquad \forall n, i, j, \ and\ t \tag{23}$$

Equation 15 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, holding inventory, and transaction costs with producers over the planning horizon. Equations 16 to 18 are the inventory accumulation constraints over the planning horizon. Equation 19 is availability constraint that restricts total amount purchased from each production source from exceeding amount available for sale in each period. Equation 20 is the requirement constraint that restricts the total amount purchased over the planning horizon from exceeding total annual throughput for each storage firm. Equation 21 is the total supply constraint per producer over the planning horizon. Equation 22 is the storage capacity constraint, and equation 23 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 to be sold. The profit maximization problem of the joint corn-soybean processing plants is defined as follows:

$$\underbrace{Maximize}_{Y_{mk}, Q_{njkt}} \; Z^K = \sum_{m=1}^{M}\left(p_m^{PR} \bullet \sum_{k=1}^{K} Y_{mk} \right) - \sum_{n=1}^{N}\left[\left(\sum_{j=1}^{J}\sum_{t=1}^{T} Q_{njkt} \right) \bullet \sum_{k=1}^{K} VC_{nk} \right] - \sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{t=1}^{T}\left[Tc_{njt} * Q_{njt} \right]$$
$$- \sum_{n=1}^{N}\sum_{j=1}^{J}\left[\left(\sum_{i=1}^{I} \omega_{nijt}^{I} + \sum_{j=1}^{J}\left(\omega_{njt}^{J} + p_{njt}^{J} \right) \right) * \sum_{j=1}^{J} Q_{njt} \right] \quad (24)$$

Subject to

$$Y_{mk} - \beta_{mn} \bullet \sum_{t=1}^{T}\sum_{j=1}^{J} Q_{njkt} \quad \leq 0 \quad \forall m, n, \; and \; k \quad (25)$$

$$Y_{mk} \quad \leq M_{mk} \quad \forall m \; and \; k \quad (26)$$

$$\sum_{t=1}^{T} Q_{njkt} \quad \leq \tau Scap_j \quad \forall n, j \; and \; k \quad (27)$$

$$\sum_{t=1}^{T}\sum_{j=1}^{J} Q_{njkt} \quad = Cap_k \quad \forall n \; and \, k \quad (28)$$

$$Y_{mk}, Q_{njkt} \quad \geq 0 \quad \forall n, j, m, k, t \quad (29)$$

Equation 24 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, variable processing costs, and transaction costs with storage firms. Equation 25 is the product balance constraint, equation 26 is sales constraint per component part, equation 27 is the supply constraint per storage level firm, equation 28 is the demand constraint per processing plant, and equation 29 is the processing level non-negativity constraint.

4.2. Consolidated Storage Supply Chain Problem

In the consolidated storage design, the production and processing level problems are the same as those of the decentralized design. However, instead of each storage firm determining its optimal decisions, a central manager simultaneously determines the optimal amount of corn and soybeans to buy, the amount of inventory to carry, and the amount to sell to the processor for each storage location (firm) over the planning horizon. The consolidated storage problem is specified as follows:

$$\underbrace{Maximize}_{x_{nijt}, Q_{njt}, SI_{njt}} Z^J = \sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{t=1}^{T}\left[\left(\omega_{njt} + p_{njt}^{J}\right)\bullet Q_{njt}\right] - \sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{t=1}^{T}\left[\left(SC_{njt} \bullet S_{njt}\right)\right] - \sum_{n=1}^{N}\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{t=1}^{T}\left[\left(\left(\omega_{nijt} + p_{nijt}^{I}\right)\bullet X_{nijt}\right) - \left(Tc_{nijt} \bullet X_{nijt}\right)\right] \quad (30)$$

Subject to

$$Q_{nj1} - \sum_{i=1}^{I} X_{nij1} + SI_{nj1} = 0 \quad \forall n, j, and\ t = 1 \quad (31)$$

$$Q_{nj2} - \sum_{i=1}^{I} X_{nij2} - SI_{nj1} + SI_{nj2} = 0 \quad \forall n, j, and\ t = 1,2 \quad (32)$$

$$Q_{nj3} - \sum_{i=1}^{I} X_{nij3} - SI_{nij2} + SI_{nij3} = 0 \quad \forall n, j, and\ t = 2,3 \quad (33)$$

$$\sum_{t=1}^{T} Q_{njt} \leq \tau FScap_j \quad \forall n\ and\ j \quad (34)$$

$$\sum_{t=1}^{T} X_{nijt} \leq N_{ni} \quad \forall i, j\ and\ n \quad (35)$$

$$\sum_{i=1}^{I}\sum_{t=1}^{T} X_{nijt} \leq \tau FScap_j\ \forall n\ and\ j \quad (36)$$

$$\sum_{n=1}^{N} SI_{njt} \leq Fcap_j \quad \forall j\ and\ t \quad (37)$$

$$Q_{njt}, X_{nijt}, SI_{njt} \quad \geq 0 \quad \forall i, j, n \text{ and } t \tag{38}$$

Equation 30 is the objective function for the central planner. It is defined as revenue from sales net the sum of the costs of buying corn and soybeans, inventory holding costs, and transaction costs with producers over the planning horizon and across all storage level firms. Equations 31-33 are the inventory accumulation constraints over the planning horizon. Equation 34 restricts amount sold from exceeding the amount stored over the planning horizon for each storage firm. Equation 35 is the availability constraint that restricts the total amount purchased from each production source from exceeding amount available for sale. Equation 36 is the requirement constraint that restricts the total amount purchased over the planning horizon from exceeding total annual throughput capacity for each storage level firm. Equation 37 restricts the amount of inventory carried by each storage firm in each period from exceeding their fixed storage capacities. Finally, equation 38 is the storage level non-negativity constraint.

4.3. Integrated Storage-Processing Supply Chain Problem

In the integrated storage-processing design, the production level problem is the same as that of the decentralized design. The decision of the integrated firm is to determine the optimal amount of corn and soybeans buy, amount of inventory to carry, and the amount components products to produce and sell. The integrated supply chain problem is algebraically defined as follows:

$$\underbrace{Max}_{X_{nijt},Q_{njt},Y_{mk},SI_{njt}} \quad Z^{PR} = \sum_{m=1}^{M}\left[p_m^{PR} \bullet \sum_{k=1}^{K} Y_{mk}\right] - \sum_{n=1}^{N}\left[\sum_{k=1}^{K} VC_{nk} \bullet \sum_{t=1=1}^{T}\sum_{j=1}^{J} Q_{njt}\right] - \sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{t=1}^{T}\left[(Sc_{njt} \bullet SI_{njt})\right]$$
$$- \sum_{n=1}^{N}\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{t=1}^{T}\left[\left(\left(\omega_{nijt}^{I} + P_{nijt}^{I}\right) \bullet X_{nijt}\right) - (TC_{nijt} \bullet X_{nijt})\right] \tag{39}$$

Subject to

$$Y_{mk} - \beta_{mn} \bullet \sum_{t=1}^{T}\sum_{j=1}^{J} Q_{njt} \leq 0 \quad \forall m \text{ and } n, \tag{40}$$

$$Y_{mk} \leq M_{mk} \quad \forall m \text{ and } k \tag{41}$$

$$\sum_{t=1}^{T} Q_{njt} \leq \tau Fcap_j \quad \forall n \text{ and } j \tag{42}$$

$$\sum_{j=1}^{J} Q_{njt} = Cap_k \quad \forall n \text{ and } t \tag{43}$$

$$Q_{nj1} - \sum_{i=1}^{I} X_{nij1} + SI_{nj1} = 0 \quad \forall n, j, \text{ and } t = 1 \tag{44}$$

$$Q_{nj2} - \sum_{i=1}^{I} X_{nij2} - SI_{nj1} + SI_{nj2} = 0 \quad \forall n, j, \text{ and } t = 1,2 \tag{45}$$

$$Q_{nj3} - \sum_{i=1}^{I} X_{nij3} - SI_{nj2} + SI_{nj3} = 0 \quad \forall n, j, \text{ and } t = 2,3 \tag{46}$$

$$\sum_{t=1}^{T} X_{nijt} \leq N_{ni} \quad \forall i, j \text{ and } n \tag{47}$$

$$\sum_{i=1}^{I}\sum_{t=1}^{T} X_{nijt} \leq \tau FScap_j \quad \forall n \text{ and } j \tag{48}$$

$$\sum_{n=1}^{N} SI_{njt} \leq Fcap_j \quad \forall j \text{ and } t \tag{49}$$

$$Q_{njt}, X_{nijt}, SI_{njt} \geq 0 \quad \forall i, j, n \text{ and } t \tag{50}$$

Equation 39 is the integrated firm's objective function. It is defined as revenue from sales of component products net the sum of purchasing costs, inventory holding costs, variable processing costs, and transaction costs with producers. Equation 40 is the product balance constraint; equation 41 is the component products sales constraint; equation 42 is the internal requirement constraint that restricts the total amount transferred from each storage firm over the planning horizon from exceeding their annual throughput. Equation 43 requires that total amount transferred from storage firms to processing plants to be equal to the processing capacity of each plant. Equations 44 to 46 are the inventory accumulation constraints. Equation 47 is the availability constraint, which restricts total amount supplied by each producer from exceeding amounts available for sale in each period. Equation 48 is the total requirement constraint, which restricts total amount supplied by all producers from exceeding the total storage level annual throughput. Equation 49 restricts the amount of inventory carried in each period from exceeding each storage firm's fixed storage capacity. Equation 50 is the non-negativity constraint.

5. 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 realistic relationships among the existing data. Furthermore, our purpose is to characterize differences in outcomes related to channel design rather than evaluate the scale of a single actual outcome. The sources of the data 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 varied cost structures in the state of Illinois, one from 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) plus premium per unit.

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 offices. 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 of 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 their per unit sales prices 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).

Transaction costs estimates are based on a study of direct and hidden costs in identity preserved corn supply chains (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 referenced 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.

6. Discussion of Results

The analyses are performed on 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 detailed results of the decentralized, consolidated, and integrated span of control designs are reported in Tables 2, 3, and 4 in the Appendix. Comparison of the performance of the performances of the designs is summarized in Table 1. The summarized results are discussed in proceeding paragraphs in terms of the global satisfaction levels, total firm level profits and total supply chain profits.

Table 1: Summary of the Performance of the Spans of Control Designs

	Spans of Control Designs		
	Decentralized ($)	Consolidated Storage ($)	Integrated Storage/Processing ($)
Global Satisfaction Levels (λ):	0.60	0.66	0.69
Supply Chain Levels			
Production	935,365.20	972,833.50	990,289.1
Storage	443,639.50	451,191.50**	
Processing	1,458,799.20	1,458,859.9	1,918,522.90***
Total Profit	2,837,803.9	2,882,884.90	2,908,842.00

** Consolidated storage profit and *** integrated storage/processing profit

The global satisfaction levels for the decentralized, consolidated, and the integrated designs are 0.60, 0.66, and 0.69. That is, under cooperative relationships, the global satisfaction in the compromise solutions of the systems increases with the amount of control. This behavior is consistent with the property of fuzzy sets, which can be characterized as follows: When the elements of a universal set are highly compatible with the properties of the universal set, the degree of membership is high. With respect to the supply chain, as the amount of control increases from the decentralized to the integrated design, the behaviors of firms are more closely aligned with the properties of the supply chain.

The total supply chain profit also increased from the decentralized to the integrated design. The total profit of the integrated design is $71,038.10 higher than that of the decentralized design and $25,957.10 higher than that of the consolidated design while the consolidated design is $45,081.00 higher than the decentralized design. That is on average firms in the integrated design are better off by $6,458.00 than firms in the decentralized design and $2,342.00 better than firms in the consolidated design, while firms in the consolidated design are $3,726.00 better off than firms in the decentralized design. Since the total flow capacity is constant in all designs, differences in profits can be attributed to constraints imposed on the extent of interaction between firms in the designs and the transaction costs associated with inter-firm exchanges.

With respect to firm level profits, the total production, storage, and processing level profits also increased from the decentralized to the integrated design. The total production level profits of the integrated design is higher than the decentralized design by $54,923.90 and higher than the consolidated design by $17,455.60 while the consolidated design outperformed the decentralized design by $37,468.30. The total storage and processing level profits of the consolidated design are $7,552.00 and $60.70 higher than that of the decentralized design. Also, the sum of the storage and processing level profits of the integrated design is $16,114.20 higher than the sum of the storage and processing level profits of the decentralized design and $8,501.50 higher than the sum of the storage and processing level profits of the consolidated design. This implies that the integrated design outperformed the decentralized and consolidated designs with respect to the combines storage and processing level profits.

In all three designs, the production level accounted for most of the total supply chain profits. This is because the production level problems were modeled with firms that had varied cost structures. This allowed for more efficient allocation decisions in the tradeoff decisions based on constraints imposed on the different designs. The storage level problems on the other hand were modeled with storage rates as proxies for the storage level cost structures and were relatively similar with only a cent per bushel difference among the firms. This resulted in tradeoff decisions and profits that were not significantly different among the designs. As expected, the least change in profits among the designs is recorded in the processing level it was modeled with as a single firm that operate operates corn and soybeans processing plants.

7. Summary and Conclusions

This study modeled, analyzed, and compared the performances of three functional spans of control designs adopted by agribusiness firms in the US grain industry. The spans of control designs were referred to a decentralized, consolidated and integrated designs. The designs were analyzed using fuzzy multi-objective linear programming and their performances were compared in terms of income distribution and the overall degree of satisfaction in their compromise solutions. The main finding of the study is that under all performance measures the integrated design outperformed the decentralized and the consolidated designs while the consolidated design outperformed decentralized design. This led to the conclusion that under cooperative relationships, increasing the amount of control in a grain supply chain enhances its performance.

It should be noted that while the differences in the total amounts of profits among the designs may not be very substantial; 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 justify the need for an agribusiness firm to focus on grain supply chain design as a potential source of competitive advantage and a rational for a firm to switch from one design to the next.

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APPENDIX

Table 2: Compromise Solution for Decentralized Controlled Design

SUPPLY CHAIN FIRMS AND ACTIVITIES		GL0BAL SATISFACTION LEVEL $\lambda = \mathbf{0.60}$				PROFIT (Dollars)
		DECISION VARIABLES				
		PROPORTION OF LAND (Acres)	COMMODITY FLOW AND INVENTORY PER PERIOD (Bushels)			
PRODUCTION LEVEL FIRMS			PERIOD1	PERIOD2	PERIOD3	
	CORN	300	46,800.0	0	0	
FIRM1			0	0	0	
	SOYBEAN	498	0	10,000	22,909.4	45,770.3
			(23,909.4)	(22,909.4)	0	
	CORN	390	24,228.0	12,001.0	25,402.0	
FIRM2			(27,403.0)	(25,402.0)	0	
	SOYBEAN	858.9	29,801.5	6,227.2	5,200.0	39,486.8
			(11,427.2)	(5,200)	0	
					0	
	CORN	626.7	0	33,625.0	71,028.0	
FIRM3			(104,653.0)	(71,028.0)	0	
	SOYBEAN	823.3.0	5,823.7	0	35,343.1	113,242.4
			(35,343.1)	(35,343.1)	0	
	CORN	940.8	11,537.3	121,614.0	24,904.7	
FIRM4			(146,518.7)	(24,904.7)	0	
	SOYBEAN	922.2	23,191.0	22,918.0	0	137,109.5
			(22,918.0)	0	0	
	CORN	319.0	0	0	49,762.0	
FIRM5			(49,762.0)	(49,762.0)	0	
	SOYBEAN	356.0	17,444.6	0	0	57,970.7
			0	0	0	
	CORN	517.9	79,752.0	0	0	
FIRM6			0	0	0	
	SOYBEAN	518.5	0	0	25,406.8	74,474.0
			(25,406.8)	(25,406.8)	0	
	CORN	304.9	0	0	46,947.3	
FIRM7			(46,947.3)	(46,947.3)	0	
	SOYBEAN	710.2	17,442.0	15228.8	0	76,092.9
			(32,670.8)	(15,228.8)	0	
	CORN	445.0	0	0	70,310.0	
FIRM8			(70,310.0)	(70,310.0)	0	
	SOYBEAN	695.0	0	33,360.0	0	76,181.4
			(33360.0)	0	0	
	CORN	1313.0	36,276.0	(171,016.0)	0	
FIRM9			(171,016.0)	0	0	
	SOYBEAN	1277.0	0	10,998.7	49,021.3	148,145.1
			(60,020.0)	(49,021.3)	0	
	CORN	1053.0	134,740.0	0	0	
FIRM10			(40,056.7)	(40,056.7)	0	
	SOYBEAN	1052.6	49,021.3	49,021.3	4,662.7	166,892.1
			0	(4,662.7)	0	
STORAGE LEVEL FIRMS						
	CORN		7,1028	40,703.3	101,325.7	
FIRM1			0	(303,24.7)	0	
	SOYBEAN		35,343.1	35,618.7	35,343.1	119,671.7
			(282.1)	0	0	
	CORN		91,289.3	121,614.0	121,614.0	
FIRM2			0	0	0	
	SOYBEAN		40,365.6	40,360.0	40635.6	136,209.3
			0	0	0	
	CORN		171,016.0	171,016.0	110,366.7	
FIRM3			0	0	0	
	SOYBEAN		49,021.3	49,021.3	49,021.3	187,758.5
			0	0	0	
PROCESSING LEVEL FIRM						
PROCESSED PRODUCTS			COMPONENT YIELD (litters for 'a' and Pounds for 'b to g')			
a) Ethanol				26,000,000.0		
b) Corn gluten meal				3,000,000.0		1,458,799.2
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						**2,837,803.60**

* Inventory values are in brackets '( )'

Table 3: Compromise Solution for Consolidated Storage Design

SUPPLY CHAIN FIRMS AND ACTIVITIES		GL0BAL SATISFACTION LEVEL $\lambda = \mathbf{0.66}$				PROFIT (Dollars)
		DECISION VARIABLES				
		PROPORTION OF LAND (ACRES)	COMMODITY FLOW AND INVENTORY PER PERIOD (Bushels)			
PRODUCTION LEVEL FIRMS			PERIOD1	PERIOD2	PERIOD3	
	CORN	69.9	0	0	10,903.4	
FIRM1			(10,903.4)	(10,903.4)	0	
	SOYBEAN	510.0	0	24,480.0	0	22,773.1
			(24,480.0)	0	0	
	CORN	390.1	0	61,361.0	0	
FIRM2			(61,631.0)	0	0	
	SOYBEAN	858.9	41,228.7	0	0	24,282.4
			0	0	0	
	CORN	626.7	104,653.0	0	0	
FIRM3			0	0	0	
	SOYBEAN	823.3	0	33,496.5	(7,670.2)	118,548.3
			41,166.8	(7,670.2)	0	
	CORN	940.8	0	0	158,056.0	
FIRM4			(158,056.0)	(158,056.0)	0	
	SOYBEAN	922.2	39,478.8	0	6,630.2	148,382.6
			(6,630.2)	(6,630.2)	0	
	CORN	319.0	0	0	49,762.0	
FIRM5			(49,762.0)	(49,762.0)	0	
	SOYBEAN	356.0	0	0	17,444.6	62,484.7
			(17,444.6)	(17,444.6)	0	
	CORN	517.9	16,803.0	25,609.0	37,340.0	
FIRM6			(62,949.0)	(37,340.0)	0	
	SOYBEAN	524.1	4,325.5	21,366.0	0	83,529.9
			(21,366.9)	0	0	
	CORN	501.8	0	60,649.3	16,622.9	
FIRM7			(77,272.8)	(16,622.9)	0	
	SOYBEAN	710.2	0	0	32,670.8	96,584.2
			(32,670.8)	(32,670.8)	0	
	CORN	445.0	0	70,310.0	0	
FIRM8			(70,310.0)	0	0	
	SOYBEAN	695.0	0	33,360.0	0	65,705.2
			(33,360.0)	0	0	
	CORN	1,312.0	61,833.3	100,148.7	0	
FIRM9			(145,458.7)	(45,310.3)	0	
	SOYBEAN	1,277.0	0	0	60,020.0	165,563.1
			(60,020.0)	(60,020.0)	0	
	CORN	1,086.6	40,145.9	140,222.8	0	
FIRM10			(140,222.8)	0	0	
	SOYBEAN	1036.0	40,259.2	12,578.7	0	184,980.5
			(12,578.7)	0	0	
HORIZONTALLY INTEGRATED STORAGE LEVEL						
	CORN		180,368.7	0	0	
FIRM1			0	0	0	
	SOYBEAN		40,259.2	33,945.6	32,670.8	
			0	0	0	
	CORN		31,508.7	333,333.0	0	
FIRM2			(30,324.7)	0	0	451,191.5
	SOYBEAN		43,15.5	33,496.5	84,094.8	
			0	0		
	CORN		121,456.0	0	333,333.3	
FIRM3			0	(60,649.3)	0	
	SOYBEAN		80,425.4	57,557.9	8,234.4	
			0	(282.1)	(564.2)	

PROCESSING LEVEL FIRM		
PROCESSED PRODUCTS	COMPONENT YIELD (litter for 'a' and pounds for 'b to g')	
Ethanol	26,000,000.0	
a) Corn gluten meal	3,000,000.0	
b) Corn gluten feed	12,500,000.0	
c) Corn Oil	1,500,000.0	1,458,859.9
d) Soybean meal	18,000,000.0	
e) Soybean oil	4,125,000.0	
f) Soybean Hull	375,000.0	
TOTAL SUPPLY CHAIN PROFIT		**2,882,884.90**

* Inventory values are in brackets '( )'

Table 4: Compromise Solution for the Integrated Storage-Processing Design

SUPPLY CHAIN FIRMS AND ACTIVITIES		GL0BAL SATISFACTION LEVEL $\lambda = \mathbf{0.69}$				PROFIT (Dollars)
		DECISION VARIABLES				
		PROPORTION OF LAND (Acres)	COMMODITY FLOW AND INVENTORY PER PERIOD (bushels)			
PRODUCTION LEVEL FIRMS			PERIOD1	PERIOD2	PERIOD3	
	CORN	300	24,956.0	21,844.0	0	
FIRM1			(21,844.0)	0	0	
	SOYBEAN	498.1	18,366.2	5,543.2	0	23,550.9
			(5,543.2)	0	0	
	CORN	390.1	30,000	31,631.0	0	
FIRM2			(31,631.0)	0	0	
	SOYBEAN	858.9	25,113.3	16,115.4	0	25,162.7
			(16,115.4)	0	0	
	CORN	626.7	33,255.2	15,221.8	56,176.0	
FIRM3			(71,397.8)	(56,176.0)	0	
	SOYBEAN	823.3	18,809.0	22,257.8	3,340.0	114,602.9
			(22,257.8)	(3,340.0)	0	
	CORN	940.8	0	131,774.7	26,281.3	
FIRM4			131,774.7	(26,281.3)	0	
	SOYBEAN	922.2	46,109.0	0	0	152,254.7
			0	0	0	
	CORN	319.0	0	0	49,762.0	
FIRM5			(49,762.0)	(49,762.0)	0	
	SOYBEAN	356.0	1,215.2	16,229.4	0	69,639.7
			(16,229.4)	0	0	
	CORN	406.9	30,324.7	32,331,0	0	
FIRM6			(32,331.0)	0	0	
	SOYBEAN	524.1	25,682.4	0	0	56,072.5
			0	0	0	
	CORN	501.8	0	37,988.5	37,988.5	
FIRM7			(77,272.0)	(39,283.5)	0	
	SOYBEAN	710.2	0	32,670.8	0	99,696.9
			(32,670.8)	0	0	
	CORN	445.0	70,310.4	0	0	
FIRM8			0	0	0	
	SOYBEAN	689.3	33,084.4	0	0	44,912.5
			0	0	0	
	CORN	844.4	54,412.8	0	71,001.3	
FIRM9			(79,001.3)	(79,001.3)	0	
	SOYBEAN	1277.0	30,000.0	0	30,020.0	180,209.5
			(30,020.0)	(30,020.0)	0	
	CORN	1418.3	0	0	235,446.0	
FIRM10			(235,446.0)	(235,446.0)	0	
	SOYBEAN	1052.6	0	16,235.5	37,448.5	224,186.8
			(53,684.0)	(37,448.5)	0	
VERTICALLY INTEGRATED STORAGE-PROCESSING LEVEL						
	CORN		24,956.0	131,774.8	0	
STORAGE FIRM1			0	0	0	
	SOYBEAN		46,109.0	32,388.7	27,531.5	
			0	(282.1)	0	
	CORN		308,377.3	0	21,844.0	
STORAGE FIRM2			0	(21,844)	0	
	SOYBEAN		51,993.4	32,388.7	37,448.5	
			0	0	0	1,918,552.9
	CORN		0	201,558.8	311,489.3	
STORAGE FIRM3			(30,324.7)	0	0	
	SOYBEAN		26,897.6	60,146.4	60,020.0	
			0	0	0	

PROCESSING LEVEL FIRM

PROCESSED PRODUCTS	COMPONENT YIELD (Litter for '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	
e) Soybean meal	18,000,000.0	
g) Soybean oil	4,125,000.0	
g) Soybean Hull	375,000.0	
TOTAL SUPPLY CHAIN PROFIT		**2,908,842.00**

- Inventory values are in brackets '( )'

SHORT SUMMARY

A fuzzy multi-objective linear programming model is used to analyze the performances of three spans of control designs that are observed in the U.S grain industry. Performance of the grain supply chain increases with amount of control and compromise.