# An Optimization Model using Nonlinear Integer Programming for a Supply Chain Network of Fresh Agricultural Products

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***Abstract* — In this paper, we focus on the optimization of fresh agricultural products supply chain network, which is very crucial for the development of rural economy. We demonstrate that the fresh agricultural products supply chain is constructed by three sub-systems: 1) Producing system, 2) Total distributed system, and 3) Retail system. We regard the supply chain network design task as a multi-objective nonlinear integer programming problem. Particularly, the objectives are to minimize the total cost of the supply chain, meanwhile to maximize customer services and capacity utilization balance. On the other hand, the supply chain network optimization process should describe the relationships between Suppliers, Plants, Distribution centers, and customers. Then we introduce an optimization algorithm using nonlinear integer programming with bounded integer variables, in which a novel local minimizer is implemented. We verify the effectiveness of the proposed algorithm by evaluating the risk of fresh agricultural products supply chain network before and after optimization. Experimental results show that using the proposed optimization the risk of the supply chain network is reduced significantly.**

***Keywords - Fresh agricultural product, Supply chain network optimization, Nonlinear integer programming, Lower bound, Upper bound***

## I. INTRODUCTION

Fresh production is very important in our daily life, and greatly influences the national economy and the people's living quality. In particular, fresh produce has its own attributes, e.g. fresh, natural wastage in circulation, short life cycle, and infection by natural environment. The above attributes greatly affect the basic actuality of fresh produce supply chain for the society[1][2]. However, the fresh produce's trade mode in China positions behind other advanced countries. Low quality of supply chain network in fresh agricultural products may promote the risk of the fresh produce circulation. Hence, how to control the risk in supply chain management is very crucial[3][4].

As is well known that, high efficient and reliable fresh agricultural products supply chain is able to satisfy the consumer requirements for fresh agricultural products[5]. On the other hand, it is a key guarantee of the suppliers' achievement for the economic benefit. Hence, it is very urgent to implement need for quantitative evaluating the reliability of the fresh agricultural products supply chain, to compute the grade scores and then discover the weak point in the supply chain, to provide some feasible countermeasures[6]. Particularly, the whole loss of agricultural fresh products amounts to 20% through 60% of the total amount of harvested products in all over the world, needing an effective supply chain management model.

Studying on the problem of agricultural products supply chain has important theoretical and practical significance for modern agricultural development[7][8]. From the point view of modern supply chain together with fresh produce, this paper aims to optimize the fresh agricultural products supply chain network using nonlinear integer programming[9]. Additionally, this paper also proposed an implementation scheme to promote the theory of modern supply chain system. Through studying on different types of fresh produce supply chain model in China, we explain how to optimize the agricultural products supply chain. Finally, paper wants to solve the contradiction between supply and demand of fresh produce, and then promote the quality of fresh agricultural products.

## II RELATED WORKS

In this section, we introduce the nonlinear inter programming technology and its application, and then discuss why this technology can be used in the problem of fresh agricultural products supply chain network optimization.

Kim et al. utilized the application of the mixed-integer nonlinear programming method to plan a combined heat and power plant in the day-ahead wholesale energy markets. The authors introduce the mixed-integer nonlinear programming system, which is made up of practical constraints, e.g.

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minimum/maximum power output and steam flow restrictions[10].

Kilinc et al. utilized the strong branching technology to reduce the size of the branch-and-bound tree for solving mixed integer nonlinear programming problems. This paper concentrates on the problem of how to utilize the unuseful information from strong branching to strengthen relaxations of mixed integer nonlinear programming problem. The inequalities span a spectrum from those that require almost no extra effort to compute to those that require the solution of an additional linear program[11].

Carrizosa et al. converted the problem of the mixed integer nonlinear program to the problem of searching a subspace with a sparse basis minimizing the sum of squares of distances between the points and their projections. Different from the existing works, the proposed framework is able to fix the level of sparseness of the resulting basis vectors, and then variable neighborhood search is proposed to this problem[12].

Hijazi et al. proposed a common structure in convex mixed-integer nonlinear programs. In the presence of such structures, the authors presented 3 improvements to the outer approximation algorithms, that is 1) a simple extended formulation, 2) a refined outer approximation, and 3) a heuristic inner approximation of the feasible region. In the end, the authors demonstrate that the techniques can be extended to perspective formulations of several problems[13].

Melo et al. proposed a novel hybrid algorithm for convex Mixed Integer Nonlinear Programming. The proposed hybrid algorithm is a modified version of the classical nonlinear branch-and-bound procedure, where the enhancements are got with the application of the outer approximation algorithm on the specific nodes[14].

Different from the above works, nonlinear integer programming has been widely exploited in many other applications, such as carbon negative electricity generation[15], global optimization applications[16], Heterogeneous parallel method[17], Generalized Disjunctive Programming[18], Linearization-based algorithms[19], Disassembly Sequence Planning[20].

## III MODELING THE FRESH AGRICULTURAL PRODUCTS SUPPLY CHAIN NETWORK

In this section, we will describe the structure of the fresh agricultural products supply chain network model. At first, we illustrate the basic structure of the fresh agricultural products supply chain in Fig.1.

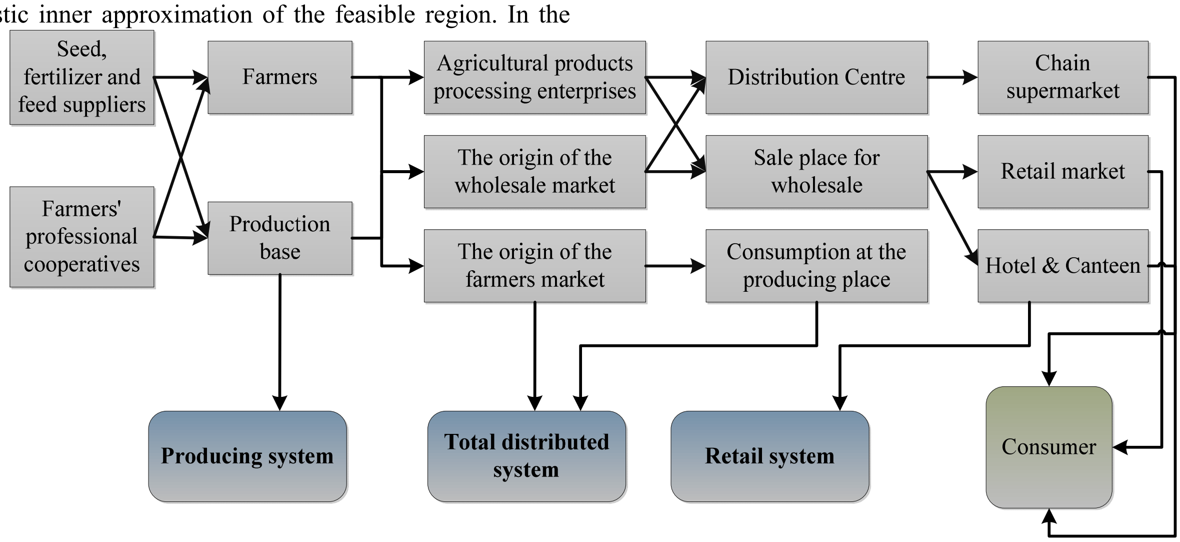


Fig. 1 Structure of the fresh agricultural products supply chain

As is shown in Fig.1, structure of the fresh agricultural products supply chain is mainly made up of three sub-systems, e.g. 1) Producing system, 2) Total distributed system, and 3) Retail system.

Fresh agricultural products supply chain is a multi-level, multi type, complex network with different kinds of functions, and Fig.1 can clear describe the fresh agricultural products supply chain. This network structure can be described as fresh agricultural products supply chain in two dimensions, namely, horizontal structure and vertical structure.

Horizontal structure refers to the core business of fresh agricultural products supply chain. However, the connection of fresh agricultural products supply chain is random with nodes chain varying. On the other hand, vertical structure refers to the amount of each level of the supplier or customer. In the fresh agricultural products supply chain, for wholesalers of fresh agricultural products origin, the number of suppliers is relatively large, which ranges from hundreds to more than tens of thousands.

In this paper, we regard the supply chain network design problem as a multi-objective nonlinear integer programming model. The objectives are designed to minimize the total cost of supply chain, meanwhile to maximize customer services and capacity utilization balance. The formal description of the supply chain network optimization problem can be explained as follows.

Supposing that there is a supply chain network $G=(N,E)$, where $N$ refers to the set of nodes and $E$ means the set of edges in the graph. In particular, $N$ consists of a set of suppliers $S$, plants $F$ and customers $C$. Obviously, the condition $N=S\bigcup F\bigcup C$ is satisfied. Supposing that the symbol $i$ refers to an index for customers, and $i$ is belonged to $I$, on the other hand, $j$ means an index for distribution centers ($j\in J$). Furthermore, $k$ denotes an index for manufacture plants ($k\in K$), and the symbol $s$ means an index for suppliers ($s\in S$). To construct the fresh agricultural products supply chain network, there are three assumptions in this model, that is 1) the number of customers and suppliers and their requirements are determined in advance, 2) the number of potential plants and distribution centers and the maximum capacities are given in advance as well, 3) customers are supplied product from only one distribution center.

Afterwards, we assume that $b_{sk}$ denotes the quantity of raw material transmitted from supplier $s$ to plant $k$, $f_{kj}$ refers to the quantity of the product transmitted from the $k^{th}$ plant to the $j^{th}$ distribution center, and the symbol $q_{ji}$ refers to the quantity of the product transmitted from the $j^{th}$ distribution center to the $i^{th}$ customer. Other definitions are given as follows.

$$z_j=\begin{cases}1, \text{ if the } j^{th} \text{ distribution center is open}\\ 0, \text{ otherwise}\end{cases} \quad (1)$$

$$p_k=\begin{cases}1, \text{ if the } k^{th} \text{ plant is open}\\ 0, \text{ otherwise}\end{cases} \quad (2)$$

$$y_{ji}=\begin{cases}1, \text{ if the } j^{th} \text{ distribution center}\\ \quad \text{provide service for the } i^{th} \text{ customer}\\ 0, \text{ otherwise}\end{cases} \quad (3)$$

For our proposed supply chain network, $C_k$ refers to the capacity of the $k^{th}$ plant, and the symbol $W_j$ denotes the annual throughput in the $j^{th}$ distribution center. $su_j$ refers to the capacity of the $j^{th}$ supplier for the raw material, $d_k$ means the requirement for the product at the $k^{th}$ customer.

where $N$ means the maximum number of distribution center, and $Q$ is the maximum number of plants.

## IV SUPPLY CHAIN NETWORK OPTIMIZATION ALGORITHM USING NONLINEAR INTEGER PROGRAMMING

Based on the above supply chain network for fresh agricultural products, in this section we discuss how to optimize this network using nonlinear integer programming. Nonlinear integer programming can be formulated as follows.

$$(P_I)\ \min f(x),\ s.t.\ x\in X_I \quad (4)$$

where $X_I\subset I^n$ refers to a bounded and closed box set which includes at least one point, and $I^n$ denotes a set of integer points in the space $R^n$.

On the other hand, we assume that function $f(x)$ follows the following conditions:

$$f(x)=\begin{cases}f(x), x\in X_I\\ +\infty, \text{otherwise}\end{cases} \quad (5)$$

Afterwards, the problem $P_I$ can be converted to a nonlinear integer programming problem as follows.

$$(P_I^*)\min f(x), s.t.\ x\in I^n \quad (6)$$

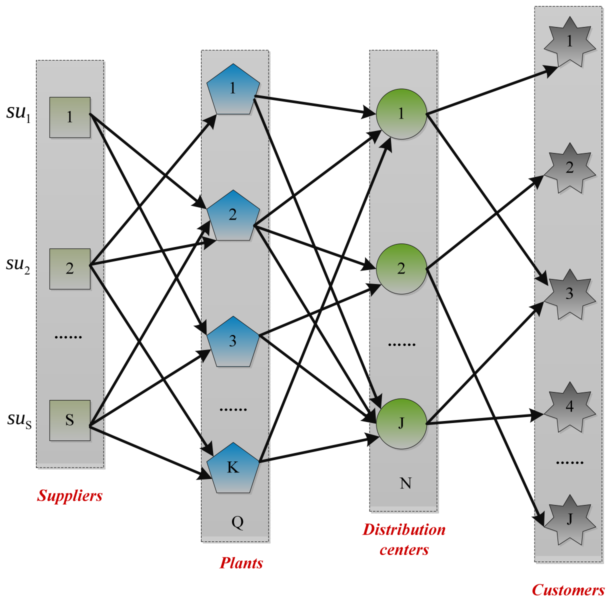


Fig. 2 Structure of supply chain network model

Furthermore, with bounded integer variables, the nonlinear integer programming can also be represented as follows.

$$\begin{aligned}&Maximize\ f(x)\\ &s.t. 1)\ g_i(x)\le b_i, i\in\{1,2,\cdots,m\}\\ &2) x\in S, S=\left\{x\middle|0\le l_j\le x_j\le u_j, x_j\in Z^+\right\}\end{aligned} \quad (7)$$

where $f(x)$ denotes the objective function, and $x=(x_1,x_2,\cdots,x_n)$ means the design vector, $g_i(x)$ is the $i^{th}$

functional constraint, $l_j$ and $u_j$ refer to the lower and upper bound on the $j^{th}$ element respectively.

In our nonlinear integer programing based supply chain network optimization, an integer point $x_0 \in \Omega$ and a constant $A$ are input. Afterwards, the following steps should be conducted.

(1) Designing a local minimizer $x_1^*$ of $f(x)$ on the space $\Omega$

(2) If $x_0$ can be used as a local minimizer of function $f(x)$ on the space $\Omega$

(3) Let $x_1^*$ be equal to $x_0$

(4) Else

(5) Seeking the neighbor $N(x_0)$ and then finding a point $x$ which is belonged to the set $N(x_0)\cap\Omega$, meanwhile $f(x)$ should be smaller than $f(x_0)$

(6) End if

(7) Let $x_0$ be equal to $x$

(8) Selecting an initial point on the space $\Omega$

(9) Minimizing the $P(X)$ on the space $\Omega$ by a local minimization algorithm.

(10) Assuming that $\tilde{x}$ is a local minimizer.

(11) Minimizing the function $f(x)$ on $\Omega$ from the point $\tilde{x}$ and then obtaining a new local minimizer $x_2^*$

(12) Let $x_1^*$ be equal to $x_2^*$

(13) Outputting the value of $x_1^*$ and the function $f(x_1^*)$ as the fresh agricultural products supply chain network optimization results

## V EXPERIMENT

To demonstrate the effectiveness of the proposed fresh agricultural products supply chain network optimization model, we collect related data about the fresh agricultural products supply chain to construct a dataset, which contains ten different supply chain networks (denoted as $\{S_1, S_2, \cdots S_{10}\}$). In this experiment, we test the risk of fresh agricultural products supply chain network before and after optimization.

To test the risk of fresh agricultural products supply chain network, we design an index system in advance, and the internal structure of the given index system is given in Fig. 3.

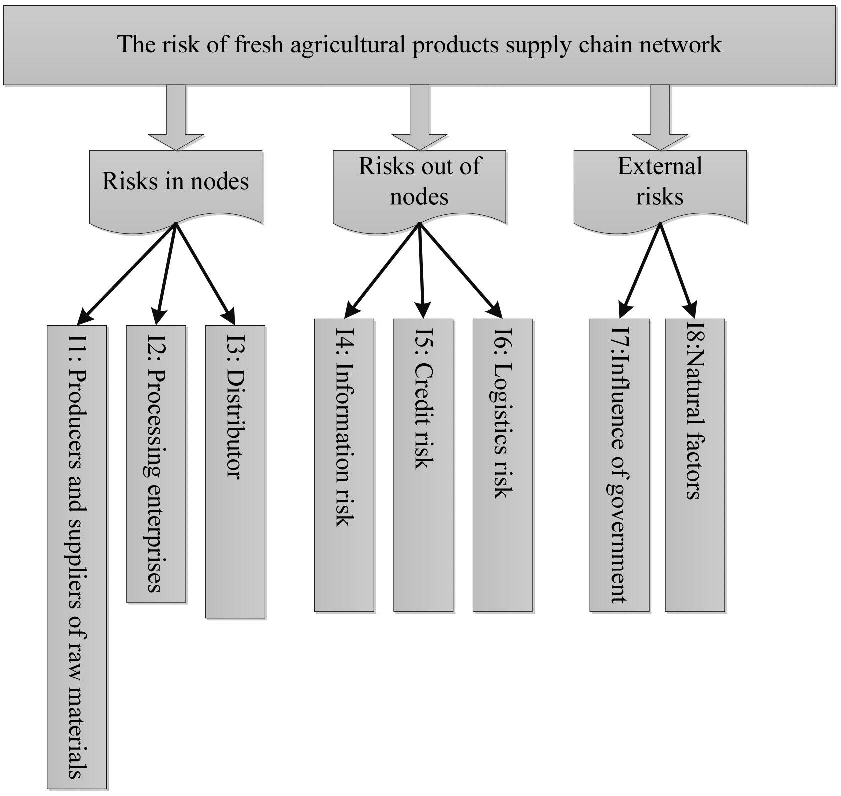


Figure 1. Fig. 3 Index system of the fresh agricultural products supply chain network risk evaluating

Afterwards, using the analytic hierarchy process technology, weight of each index is calculated, and the results are shown in Table.I as follows.

TABLE. I WEIGHTS OF THE ABOVE INDEX SYSTEM.

| ID | Weight |
|---|---|
| I1 | 0.108 |
| I2 | 0.205 |
| I3 | 0.048 |
| I4 | 0.165 |
| I5 | 0.136 |
| I6 | 0.179 |
| I7 | 0.124 |
| I8 | 0.034 |

Then, we will compare the risk evaluating performance of our proposed optimization algorithm, and the experimental result is given in Fig. 4.

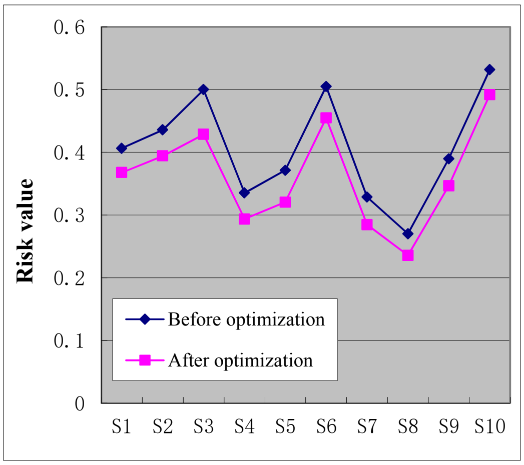


Fig. 4 Risk value of the fresh agricultural products supply chain network

As is shown in Fig. 4, we can see that using the proposed supply chain network optimization algorithm, risks of supply chain network decrease significantly, and the average risk value before and after optimization are 0.407 and 0.362 respectively.

## VI. CONCLUSIONS

This paper presented a novel fresh agricultural products supply chain network optimization method using nonlinear integer programming. The main innovations of this paper lie in that we regard the supply chain network designing task as a multi-objective nonlinear integer programming problem. Moreover, we aim to minimize the total cost of supply chain, maximize customer services and capacity utilization balance. Next, a novel supply chain network optimization algorithm for fresh agricultural products utilizing nonlinear integer programming with bounded integer variables is proposed. Experimental results prove the effectiveness of our optimization model.

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