Integrated Logistics and Transportation Routing in Rural Logistics System

T S Sinaga¹,² and S N Bahagia¹

¹Faculty of Industrial Technology, Bandung Institute of Technology, Bandung, Indonesia
²Department of Industrial Engineering, Faculty of Engineering, University of Sumatera Utara, Medan, Indonesia
tutie_rani@yahoo.co.id, senatornurb@yahoo.co.id

Abstract. The agricultural distribution problem of Rural Logistics System is addressed in this paper to improve farmers’ income by minimizing annual total cost. The system consists of three entities: (i) logistics terminal, (ii) distribution warehouses, and (iii) industries. The logistics terminal collects agricultural products from farmers’ crops, which are stored in distribution warehouses, which are further distribution based on demand of industries. This study developed non-linear mix integer programming model to minimize the annual total costs by incorporating (i) the approach of coordinated planning system, (ii) concept of echelon stock, (iii) single time cycle policy and (iv) transportation route. Many constraints were developed using various criteria. Feasible solution to the mathematical model was obtained by using heuristics method by Clarke and Wright.

Keywords: integration, echelon concept, annual cost, nonlinear mix integer programming

1. Introduction

Contribution of the agricultural sector to the Indonesian economy continues to increase, both on gross domestic product and employment creation for people. However, improvement of this sector is not always accompanied by the increasing of farmers’ income. The tendency is brokers collect the products directly from the gate of farmers to make low selling price of agricultural product in rural area. Therefore, Government focuses on the improvement strategy of logistics system in rural area, such as by reducing cost to bring benefits to farmers’ income.

Rural Logistics System can solve the problems of distribution of agricultural products, the availability of products and improve the living standards of farmers [1]. The Rural Logistics System aims to increase farmers’ income, reduce the risk of agricultural products, and encourage integrated rural-urban development [2]. Rural Logistics Systems can also create new markets as the urban market becomes saturated [3].

Rural Logistics System is the same as the logistics system in general, handles all logistical activities that are related to the delivery of products from or to rural area to increase farmers’ income. The Rural Logistics System is almost identical to the urban logistics system, it simply refers to the production of rural communities and other economic activities such as the provision of transportation, packaging, processing, storage and other related activities [4]. Rural Logistics System is supply chain networks involving upstream and downstream farmers, outlets, logistics terminal, wholesalers, industries or
retailers, and final consumers who need agricultural products or services. There are two types of product flow included in the rural logistics discussion which are agricultural logistics and rural business logistics [5].

Issue of rural logistics in Indonesia is how to bridge the interests of farmers in rural areas to get a reasonable and stable selling price of agricultural products while still protecting the interests of consumers in urban areas in terms of availability and quality. Therefore, implementation of rural logistics systems is very important to support the government's efforts to realize an effective integrated logistics system, so it can enhance the welfare of the community. The Government has built Sub Logistics Terminal (STA) as one of many entities in Rural Logistics System, however in this research we focused only to 3 echelons of supply chain. Distribution network from logistics terminal to industries of a rural logistics system is shown in Figure 1 below:

![Distribution Network Model in Rural Logistics System](image)

**Figure 1. Distribution Network Model in Rural Logistics System**

The figure shows that rural logistics system has a district logistics terminal and multi distribution warehouses to meet the demands from many industries that scattered away from rural locations. Agricultural products from smallholder farmers collected to logistics terminal for sorting and repackaging products, according to its standard. Furthermore, agricultural products were sent to Distribution Warehouse before delivered to industries that need them.

Relationship among entities in supply chain needs to be considered, because it is realized that industry is one of the targets to reduce cost of the system [6]. This discussion would be very helpful in determining the business strategy of the Rural Logistics System in order to provide better service to customer, by implementing competitive prices and increasing farmers’ income. This model answers the most important question in logistics management: how many products that must be ordered from industries to distribution warehouse and from distribution warehouse to Logistics terminal? Since rural logistics system is the most famous and applicable in many countries, numerous conceptual models of
rural logistics system have been developed by researchers and academicians. However, a model to answer this problem has never been developed before.

This paper is organized as follows. Section 2 describes methodology of research, including component of model are introduced. Section 3 presents mathematical model and an algorithm to search feasible solution. In Section 4, some numerical examples are presented to illustrate the effectiveness of the model. Finally, this paper gives the conclusion in Section 5.

2. Methodology

Mathematical model of rural logistics system was developed from an optimization model of integrated three echelon supply chain system [7] and accommodated optimal model of transportation with balanced workload [8]. Based on integrated concept [7], solving logistics problems requires an integrated systemic approach using the following steps i.e.: developed a coordinated planning, implementation of echelon stock concept and single time cycle policy. Liu [8] suggested to schedule a set of routes to deliver the commodities at minimum total distance travelled, considering vehicle capacity and balance of vehicle's workload, to minimize the number of vehicles used. These heuristic approach consists of three phases. First, tracing an initial feasible solution using a savings-based method. The second is improvement of route using five steps of one-point movement. Last phase is balancing workload and delivery time. As a constraint, in this paper route of vehicle did not consider balances of vehicle's workload.

2.1. Component of Model

In this section component of model was investigated. This paper focused to Annual Cost of Rural Logistics System, including inventory costs and transportation costs. Problem definition for this model is “how is the rural logistics system that can guarantee product’s availability and increase farmers’ income by minimizing annual cost?” Structural aspects from this model consists only three entities which are: a logistics terminal, distribution warehouses, and industries. Its functional aspect considered the flow of agricultural product, information, and money among the entities.

The performance criteria used in this model is minimization annual cost of the Rural Logistics System, including order cost, holding cost, shortages cost, opportunity cost, and the transportation cost at the logistics terminal and distribution warehouse. Expected performance criteria and the decision variables set in the developed model are:

1. At Logistics Terminal: annual cost, order lot sizing and order period
2. At Distribution Warehouse: quantity order and , order frequency, frequency of delivery, and unit of product that can be served by a certain vehicle.

The assumptions underlying the models in this paper are 1) Demand has a normal distribution 2) Demand that cannot fulfilled will be lost (lost sales) and 3) If products are inconsistent with consumer needs, it will be returned and this may result in risk of damage. There are various constraints with rural network problem, such as limited vehicle, single item, fixed cost of vehicles, etc. In this paper, vehicle used both revised driving route from logistics terminal to distribution warehouse and actual driving route at distribution warehouse to customers.

2.2. Model Formulation

Mathematical model for integration system in rural logistics is described as follows

a. Index Parameters Set
   
   \[ I \quad : \text{number of industries} \]
   \[ J \quad : \text{number of distribution warehouses (DW)} \]
   \[ K \quad : \text{number of vehicles used} \]
   \[ U \quad : \text{number of nodes in transport route } U = I \cup J \]

b. Indices
   
   \[ d \quad : \text{length of distances between node in distribution warehouse area} \]
g : number of products to serve by vehicle
h : number of demands from industry
i : index for industry
j : index for distribution warehouse
k : index of vehicle
m : origin number of routing node
n : destination number of routing node
c. Problem Parameters Set

\( C_{ai} \) : annual cost (Rp/year)
\( C_{dj} \) : Annual cost at distribution warehouse (Rp/years)
\( CP_j \) : total inventory cost per year at distribution warehouse (Rp/years)
\( CT_j \) : total transportation cost per period at distribution warehouse (Rp/years)
\( A_j \) : order cost at DW\(_j\) (Rp/Order)
\( D_j \) : demand at DW\(_j\) (unit/years)
\( D_{ij} \) : demand from industry, to DW\(_j\) (unit/years)
\( h_m \) : demand have to be delivered to industry from DW\(_j\) (unit/delivery)
\( \mu_j \) : mean of demand DW\(_j\) from DW\(_j\) to logistics terminal, in certain leadtime
\( \mu_{ij} \) : mean of demand to delivery from DW\(_j\) to industry-i. (unit/delivery)
\( \sigma \) : standard deviation of demand to delivery from DW\(_j\) to industry-i. (unit/delivery)
\( \theta_{m} \) : mean of demand delivered from DW\(_j\) to node m (unit/delivery)
\( H_j \) : holding cost per unit per year at DW\(_j\) (Rp/unit/years)
\( z \) : \( z \) value on standard normal distribution for a level \( P(x=\theta_m) \)
\( L_j \) : lead time from DW\(_j\) to logistics terminal (years)
\( S_j \) : shortage cost per unit per period (Rp/unit/delivery)
\( P_j \) : opportunity cost per unit per period (Rp/unit/delivery)
\( l \) : leadtime of Distribution Warehouse
\( A_o \) : order cost at logistics terminal (order/year)
\( D_o \) : demand at logistics terminal (unit/year)
\( f_{g_{jk}} \) : holding cost at logistics terminal (Rp/unit/tahun)
\( v_{jk} \) : transport volume of vehicle-k at DW\(_j\) (piece/vehicle)
\( os_k \) : set up cost vehicle-k used at DW\(_j\) (Rp/delivery)
\( ob_k \) : loading and unloading cost at DW\(_j\) for each delivery (Rp/unit/delivery)
\( ot_{nm} \) : transportation unit cost from node m to node n at DW\(_j\) (Rp/km/delivery)
\( op_{ij} \) : opportunity cost per unit at DW\(_j\) (Rp/unit/delivery)
\( ok_{ij} \) : reverse cost per unit at DW\(_j\) (Rp/unit/delivery)
\( d_{mn} \) : length of distance from node m to node n at DW\(_j\) (km)
\( x_{mnk} \) : 1 if vehicle k travels directly from node n to m , 0 for otherwise.
\( y_{jk} \) : 1 if vehicle k travels directly from DW\(_j\) to customer i, 0 for otherwise
d. Decision Variables
1. At Logistics Centre:
\( Q_o \) : order lot sizing (unit)
\( T_o \) : order period (years)
2. At Distribution Warehouse:
\( Q_j \) : quantity order (units)
\( N_{ij} \) : order frequency to logistics terminal
\( N_{ij} \) : frequency of delivery from DW\(_j\) to industry i in leadtime (delivery/period)
\( N_{ij} \) : frequency of product delivery from DW\(_j\) to industry i per years (delivery/period)
\( g_{jk} \) : unit of product to serve by vehicle-k at DW\(_j\) (unit/vehicle)
The objective function of the model is to minimize the annual total cost \( (C_{\text{tot}}) \) on a certain rural logistic system. Total annual cost can be calculated by summing annual costs at the logistics terminal (Co) and annual cost at DW (\( C_d \)).

\[
C_{\text{tot}} = C_o + C_d \tag{1}
\]

Furthermore each component’s cost is described and calculated in the following way: The annual cost incurred at distribution warehouse was the sum of the annual inventory cost \( (CP_j) \) with the annual transportation cost on all DWj \( (CT_j) \).

\[
C_d = \sum_{i \in j} (CP_j + CT_j) \tag{2}
\]

\[
CP_j = A_j x^d_{j} + H_j \left[ \frac{Q_j}{2} + R_j - L_j \cdot D_j \right] + D_j. N_j \cdot S_j \cdot \sum_{k \in K_j} \int_{0}^{\infty} (g_{jk} - v_{jk}) \cdot f(g_{jk}) \, dg_{jk} +
\]

\[
D_j. N_j \cdot S_j \cdot \sum_{k \in K_j} \int_{0}^{\infty} (v_{jk} - g_{jk}) \cdot f(g_{jk}) \, dg_{jk} \tag{3}
\]

\[
CT_j = \sum_{i \in j} N_i \cdot K_j \cdot o_{s_i} + o_{t_i} \cdot v_{jk} + \sum_{m \in U} \sum_{n \in U} O_{mn} \cdot D_{mn} \cdot x_{mnk} + o_{p_j} \cdot \sum_{k \in K_j} \int_{0}^{\infty} (g_{jk} - v_{jk}) \cdot f(g_{jk}) \, dg_{jk} \tag{4}
\]

The annual costs incurred at the logistics terminal were only order cost, inventory cost, and transportation cost, due to the level of demand. Demand calculation in logistics terminal was justified only based on Distribution Warehouse needs.

\[
C_o = A_o \frac{D_o}{Q_o} + H_o \left[ \frac{Q_o}{2} + R_o - \sum_{i \in j} (L_o + L_j) D_j \right] + \sum_{i \in j} \frac{D_i}{Q_i} (o_{s_i} + o_{t_i} + o_{d_i} \cdot o_{c_i}) \tag{5}
\]

Subject to:
1. \( D_o = \sum_{i \in j} D_j \) \( \forall j \in J \)
2. \( \frac{Q_o}{D_o} = N_j \frac{Q_j}{D_j} \) \( \forall j \in J \)
3. \( D_j = \sum_{i \in j} D_{ij} \) \( \forall j \in J \)
4. \( D_{ij} = N_i \cdot \mu_{ij} \) \( \forall j \in J \)
5. \( \mu_{ij} + 2 \sigma_{ij} = \theta_m \) \( \forall m \in I_j \)
6. \( \sum_{k \in K_j} \sum_{m \in U} x_{mnk} = 1 \) \( \forall j \in I \)
7. \( \sum_{m \in U} x_{mnk} - \sum_{m \in U} x_{nmk} = 0 \) \( \forall n \in U; \forall k \in K_j \)
8. \( \sum_{m \in U} x_{mnk} = y_{jk} \) \( \forall n \in U; \forall k \in K_j \)
9. \( \sum_{m \in U} x_{nmk} = y_{jk} \) \( \forall n \in U; \forall k \in K_j \)
10. \( \sum_{m \in U} \theta_m \sum_{m \in U} x_{mnk} = v_{jk} \) \( \forall k \in K_j \)
11. \( \sum_{m \in U} \sum_{n \in U} x_{mnk} - u \sum_{m \in U} y_{jk} \leq 0 \) \( \forall k \in K_j \)
12. \( x_{mnk} \cdot x_{nmk} \leq 1 \) \( \forall m, n \in U; \forall k \in K_j \)
13. \( Q_0 \geq 0 \) \( \forall j \in J \)
14. \( Q_j \geq 0 \) \( \forall j \in J \)
15. \( N_j \geq 0 \) \( \forall j \in J \), integer
16. \( v_{jk} \leq 0 \) \( \forall k \in K_j \)
17. \( y_{jk} = 1 \) if \( \sum_{m \in U} x_{mnk} > 1 \) or \( 0 \) for other \( \forall k \in K_j \)
18. \( x_{mnk} \geq 0 \) \( \forall k \in K_j \)
19. \( \sum_{m \in U} h_m \{ \sum_{n \in U} x_{mnk} \} = g_{jk} \) \( \forall k \in K_j \)

Constraint (1) ensures that demand of warehouse is fulfilled, and (2) present single cycle time policy to the model. Constraint (3) states that demand of a distribution warehouse is a sum form industries' demand and (4) is be used to find demand of each industry. Constraint (5) shows sum of demand delivered
from DW$_i$ to consumer $i$. Constraint (6) ensures that convenience industry is placed on exactly one route. Constraint (7) shows the flow constraints. Constraint (8) and (9) ensure vehicles are assigned to a route from distribution warehouse to the industry, so at least one vehicle link goes to the depot and one leaves the industry. Constraints (10) and (11) impose the maximal workload that can be by brought each vehicle. Constraint (12) ensures that the number of vehicle route must be smaller or equal to the number of nodes that enter into the solution. Constraints (14)-(17) are non negativity. Constraint (18) is to choice vehicle route.

2.3. Solution Procedure

The proposed annual cost problem or rural logistics system needs an effective solution method to obtain the optimal solution. The formulation of optimization model is nonlinear mix integer programming problems. Since integration inventory with vehicle routing are larger-scale application, it is very difficult to solve it with ordinary NLP method, hence developed heuristics procedure to solve the problem. In this research, $Q^*_i$ can be obtained if $\frac{dcot}{Q_i} = 0$ for $N_j$, $N^*_j$ can determined using heuristic approach [7] by assuming that $N_j$ is a continuous number. The determination of $x_{mnk}$ value did not use the heuristic method proposed by Liu [8]. It will be developed by using heuristic method that was proposed by Clarke and Wright [9]. This approach can solve the mathematical model and has capability to produce feasible solutions.

3. Result and Discussion

In this section, a rural logistics system is proposed to test this model. The system has a logistics terminal and five distribution warehouses in each region. Each warehouse unit must fulfill demand of process industries. Agricultural products are supplied to the logistics terminal and forwarded to distribution warehouses before being distributed to industries in the region. The hypothetical data was used in this model test. Furthermore, the computation of heuristic procedure was constructed by Visual Basic to improve efficiency and quality of solution. The implementation results for the logistics system conditions considered are as follows:

1. The optimal solution of vehicles route for each distribution warehouse can be seen in Table 1 below:

| Distribution Warehouse | Vehicle | Route          | Workload (unit) | Distance (km) |
|------------------------|---------|----------------|-----------------|---------------|
| 1                      | 1       | DW1-3-4-2-DW1  | 111,954         | 59            |
| 2                      | 1       | DW2-2-3-DW2    | 113,424         | 28            |
|                        | 2       | DW2-1-5-4-DW2  | 120,488         | 88            |
| 3                      | 1       | DW3-1-3-4-DW3  | 106,27          | 65            |
|                        | 2       | DW3-2-5-6-DW3  | 116,564         | 93            |
| 4                      | 1       | DW4-2-4-DW4    | 111,072         | 50            |
|                        | 2       | DW4-1-3-DW4    | 81,564          | 49            |
| 5                      | 1       | DW5-1-3-DW5    | 96,66           | 36            |
|                        | 2       | DW5-4-5-DW5    | 117,148         | 53            |
|                        | 3       | DW5-2-6-DW5    | 81,762          | 67            |

2. Detail feasible solutions for quantity order, order frequency and annual cost on distribution warehouses are shown Table 2.
### Table 2. feasible solution for quantity order, order frequency and annual cost

| Level | N_j | Q* (unit) | T* (year) | TC* (Rp) |
|-------|-----|-----------|-----------|----------|
| DW1   | 2   | 1.655     | 0.1769    | 2.371.842,52 |
| DW2   | 2   | 2.845     | 0.1852    | 2.865.931,41 |
| DW3   | 2   | 1.627     | 0.1695    | 2.687.246,74 |
| DW4   | 2   | 1.639     | 0.1625    | 2.468.167,40 |
| DW5   | 2   | 2.299     | 0.1916    | 1.939.932,99 |

**Total (C_d) (Rp)** 12.333.121,05

The total annual cost for a rural logistics system is Rp 61.134.868.83, with order quantity at logistics terminal is 21.178 units, length of cycle 0.376 years, and annual cost Rp. 48.801.747.78.

In this paper, we analysed a mathematical model of the annual cost problem. The constraints introduced were capacity of vehicle and risk cost when delivered products did not fit customer requirements, for instance shortage cost and reverse cost. To determine N_j*, we used Y1 and Y2 as influence factors and they manifest the difference from previous model [7]. The inventory rule in this condition is applicable when producers coine to consumers with unclear information about their needs so enhance the risk of excess supply.

The inventory rule in this condition is when producers come to consumers with unclear information about the needs of consumers and producers so enhance the risk of excess supply.

### 4. Conclusion
A nonlinear mix integer programming model was proposed to solve annual cost problem in Rural Logistics System. The model incorporated coordinated planning, stock echelon concept, single cycle time policy, and transportation route. Heuristic procedures were developed to solve the formulated mathematical model. The solutions of numeric example were obtained by computation effort according to the proposed procedure. The research contribution is on the more effective and reliable algorithm, regarding the solution quality and run time reduction. Potential future research can be done by considering farmers as an entity of Rural Logistics System with a stochastic demand.

### Acknowledgment
Authors would like to thank the Ministry of Finance, Indonesia for the BUDI-DN/LPDP Scholarship.

### 5. References
[1] Yun Z and Lingyun S 2011 Rural logistics demand forecasting based on the BP neural network method. Proc. of Int. Conference on Management and Service Science pp 1-5
[2] Xu C H and Huang J 2014 Research on manufacturing engineering in agriculture with construction of China's rural logistics system. Applied Mechanics and Materials 540 pp 532-536
[3] Viswanadham N D and Ramakrishna D 2007 Achieving Rural & Global Supply Chain Excellence, The Indian Way, Center for Global Logistics and Manufacturing Strategies. (Gachibowli: India School of Business) pp 15 – 34
[4] Zhou Y L, Shao W Q, Bai D M and Su L U 2016 Study on The Modes for The Development of Rural Logistics in The Process of New Urbanization. Proc. of Conference Logistics Sci-Tech. 4 (May) pp 23–32
[5] Zhang, Xi-Zhou, Chen L and Liu J 2010 The Mechanism of Rural Business Logistics Operation in Mainland China A Research Based on Home Appliances Going to Countryside Management and Service Science (MASS). Proc. of Int. conference on Management and Service Science China pp 1-5
[6] Stank, Theodore P, Traichai and Patrick A 1998 Logistics Strategy, Organizational Design, And Performance in A Cross-Border Environment. Transportation Research Part E (Logistic and Transp. Rev) 34(1) pp 75-86

[7] Nur Bahagia S 1999 Model optimasi integral sistem rantai nilai tiga eselon. Proceedings of Seminar Sistem Produksi (Bandung: Departement of Industrial Engineering-ITB) 4 pp 1-9

[8] Liu C M, Chang T C and Huang L F 2006 Multi-Objective Heuristics for the Vehicle Routing Problem. International Journal of Operations Research 3(3) pp 173-181

[9] Clarke G and Wright J 1964 Scheduling of vehicles from a central depot to a number of delivery points. Operations Research 12(4) pp 568-581