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Effective wood logistics management: Utility-based self-control transportation strategy

Meng Li, Ronghua Ji, Lairong Chen*

The School of Technology, Beijing Forestry University, Beijing, (CHINA)

College of Information and Electrical Engineering, China Agriculture University, Beijing, (CHINA)

The School of Technology, Beijing Forestry University, Beijing, (CHINA)

E-mail : clrong@bjfu.edu.cn

ABSTRACT

Wood logistics management has drawn a lot of attentions in recent wood transportation research. It is essential to research the wood logistics management for wood transportation optimization. In this paper, we analysis the wood logistics management pattern, construct a wood transportation optimal model based on economy concept, which is called utility theory. Then we research the solutions to the optimal wood transportation and give out the optimal wood control strategy when the transportation cost is minimized. Simulations show that our proposed scheme can achieve cost minimized and optimal control can be obtained.

KEYWORDS

Wood logistics management; Effective control; Transportation; Self-optimized; Utility function.

INTRODUCTION

Wood transportation is one of the core parts in wood logistics network, which means transporting wood from logistics centers to wood required places after being cut from forest regions[1]. It includes transportation between forest regions and logistics centers, between logistics centers and wood required places, and timber management in the transportation step. In order to control the transportation cost, it is essential to research the transporting timber control in wood logistics networks, which has attracted a great deal of research interests all over the world.

Transporting timber control is a challenging issue for transportation cost control in wood logistics networks, because timber transportation cost occupy a large proportion in the total cost of wood logistics system[2]. Lots of works have been down on transportation route optimization[3-6], but the transporting timber control is one of the key problems need to be researched to control the transportation cost after the route optimization. In this work, we take a utility-based approach to transporting timber control problem in wood logistics networks, that utility theory has been widely used to solve the control and optimization problems in logistics networks. In this paper, the utility function will consider the transportation cost, storage cost and congestion cost. Some kind of works have been down in our previous work[7], which didn't consider the congestion cost for the optimal timber control.

The paper is organized as follows. The system model and the utility function is analyzed in Sec.2 and the solutions to the model and the related algorithms will be presented and discussed in Sect. 3. Sect. 4 give out the numerical simulation results and it is concluded in Sect. 5

SYSTEM MODEL

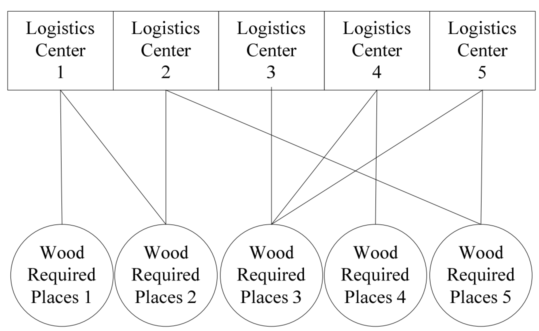

Figure 1 : System model

We focus our analysis on the timber control in the wood logistics networks (Shown in Figure 1). In our model, the logistics centers are assumed to be located in the wood cutting place. Assuming there are $M = \{1, 2, 3, \ldots, m\}$ logistics centers, and $N = \{1, 2, 3, \ldots, n\}$ wood required places, the transportation expense between logistics center i and wood required place j is C_{ij}, then C_{ij} can be expressed as follows

$$C_{ij} = r_{ij} d_{ij} W_{ij} \quad \textbf{(1)}$$

Where r_{ij} is the transportation expense rate between logistics center i and wood required place j, in unit of transportation expense per kilometers per ton. d_{ij} is the transportation distance between logistics center i and wood required place j, and W_{ij} is the timber volume between logistics center i and wood required place j.

Generally, there is an upper-limit of timber volume for logistics center, which is given by

$$\sum_{j=1}^{n} W_{ij} = W_{i1} + W_{i2} + \ldots + W_{in} \le W_i \quad \textbf{(2)}$$

Where W_i is the storage up limit of logistics center i.

For each logistics center, in order to transport timber for wood required places, it will have storage cost. Let S_{ij} denote the storage cost of logistics center i store timber for wood required place j. And S_{ij} can be expressed as

$$S_{ij} = \frac{\mu_{ij}}{2}\left(W_{ij} - \overline{W_i}\right)^2 \quad \textbf{(3)}$$

Where μ_{ij} is the storage unit cost, $\overline{W_i}$ is a storage threshold. In the wood transportation, some wood may be congested on the road, had has additional cost, which can be expressed as

$$D_{ij} = \alpha_{ij} - \pi_{ij} W_{ij} \quad \textbf{(4)}$$

Where α and π_{ij} are positive congestion cost parameter. Then the utility function (cost function) between logistics center i and wood required places j can be expressed as

$$\begin{aligned} U_{ij} &= C_{ij} + S_{ij} + D_{ij} \\ &= r_{ij} d_{ij} W_{ij} + \frac{\mu_{ij}}{2}\left(W_{ij} - \overline{W_i}\right)^2 + \alpha_{ij} - \pi_{ij} W_{ij} \\ &= \left(r_{ij} d_{ij} - \pi_{ij}\right) W_{ij} + \frac{\mu_{ij}}{2}\left(W_{ij} - \overline{W_i}\right)^2 + \alpha_{ij} \end{aligned} \quad \textbf{(5)}$$

When employing utility function to solve the timber control problem, we first have to understand a very important concept, i.e. utility actually reflects cost here. Based on the model, we develop a utility function that performs the timber control in wood logistics networks. The utility function is a function of all transport routes can be expressed as

$$\begin{aligned} U &= \sum_{i=1}^{m}\sum_{j=1}^{n} U_{ij} \\ &= \sum_{i=1}^{m}\sum_{j=1}^{n}\left(\left(r_{ij} d_{ij} - \pi_{ij}\right) W_{ij} + \frac{\mu_{ij}}{2}\left(W_{ij} - \overline{W_i}\right)^2 + \alpha_{ij}\right) \end{aligned} \quad \textbf{(6)}$$

Note that (6) demonstrates the utility functions interdependence among logistics centers and wood required places. In the utility-based framework, it is desirable to minimize the cost earned by logistics networks. Then, as our objectives here are to minimize the utility function under upper-constraint of timber for logistics center, the proposed utility minimization problem can be expressed as follows.

$$\begin{aligned} \min(U) &= \min\left(\sum_{i=1}^{m}\sum_{j=1}^{n} U_{ij}\right) \\ &= \min\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\left(r_{ij} d_{ij} - \pi_{ij}\right) W_{ij} + \frac{\mu_{ij}}{2}\left(W_{ij} - \overline{W_i}\right)^2 + \alpha_{ij}\right)\right) \end{aligned} \quad \textbf{(7)}$$

Subject to

$$\sum_{j=1}^{n} W_{ij} = W_{i1} + W_{i2} + \ldots + W_{in} \le W_i \text{,}$$

for all $i \in M, M = \{1, 2, 3, \ldots, m\}$ **(8)**

In the above optimization problem, the minimization can be achieved with optimized timber level. Formula (7) is the total utility level of the transportation networks. Formula (8) is the crucial timber constraint of every logistics centers. Solving the optimization problem of formula (7) and (8), yielding in finding the optimized timber control of every logistics centers under constraint to minimize the total cost.

SOLUTIONS

In this section, the dynamic optimization programs and solutions to the utility function (7-8) will be discussed.

Definition 1 A set of controls vectors $\{W_{ij}^*\}$ constitutes an optimal solution to the control problem (7)-(8) if for every $i \in N$, there exists $U\left(\{W_{ij}^*\}\right) \geq U\left(\{W_{ij}\}\right)$.

As a solution to formulas (7) and (8), $\{W_{ij}^*\}$ is a set of self-optimized solutions to minimize the utility function. Every transportation routing ij has its own self-optimized and rational solution $\left[W_{ij}^*\right]$. No one can achieve the optimal utility level by making individual changes in its own transportation. All work cooperatively to minimize the utility function. Generally, we have

$U\left(\{W_{ij}^*\}\right) \geq U\left(\{W_{ij}\}\right)$.

Theorem 1 Existence of Optimal Solution A set of controls vectors $\{W_{ij}^*\}$ to the control problem (7)-(8) exists.

Proof:

The utility function (7-8) can be solved by Lagrange multiplier technique. The Lagrange equation for the optimization problem in (7-8) is

$$F = \sum_{i=1}^{m}\sum_{j=1}^{n}\left(\left(r_{ij}d_{ij} - \pi_{ij}\right)W_{ij} + \frac{\mu_{ij}}{2}\left(W_{ij} - \overline{W_i}\right)^2 + \alpha_{ij}\right) - \sum_{i=1}^{m}\lambda_i\left(\sum_{j=1}^{n}W_{ij} - W_i\right) \quad \textbf{(9)}$$

By taking the derivative of (9), we get

$$dF = \sum_{i=1}^{m}\sum_{j=1}^{n}\left(\left(r_{ij}d_{ij} - \pi_{ij}\right) + \mu_{ij}W_{ij} - \lambda_i\right)dW_{ij} \quad \textbf{(10)}$$

Let the partial derivative to be zero, and then we have

$$r_{ij}d_{ij} - \pi_{ij} + \mu_{ij}W_{ij} - \lambda_i = 0 \quad \textbf{(11)}$$

Solve the above formulas and the solutions are

$$W_{ij} = \frac{\lambda_i - \left(r_{ij}d_{ij} - \pi_{ij}\right)}{\mu_{ij}} \quad \textbf{(12)}$$

Substituting formula (8) into (12), we can find that λ_i follows the below equation.

$$\sum_{j=1}^{n}\frac{\lambda_i - \left(r_{ij}d_{ij} - \pi_{ij}\right)}{\mu_{ij}} = W_i \quad \textbf{(13)}$$

Then we can get λ_i as

$$\lambda_i = \frac{W_i + \sum_{j=1}^{n} \frac{\left(r_{ij} d_{ij} - \pi_{ij}\right)}{\mu_{ij}}}{\sum_{j=1}^{n} \frac{1}{\mu_{ij}}} \quad \textbf{(14)}$$

Substituting formula (14) into (12), we can get the final solutions to the optimized power W_{ij} as a formula of λ_i.

$$W_{ij} = \frac{W_i + \sum_{j=1}^{n} \frac{\left(r_{ij} d_{ij} - \pi_{ij}\right)}{\mu_{ij}} - r_{ij} d_{ij} \sum_{j=1}^{n} \frac{1}{\mu_{ij}}}{\mu_{ij} \sum_{j=1}^{n} \frac{1}{\mu_{ij}}} \quad \textbf{(15)}$$

As we have solve the optimization problem based on the Lagrange multiplier approach. As being proposed in the above, the Lagrange multiplier approach results in different solutions for every logistics centers.

SIMULATIONS

TABLE 1 : Simulation Parameters

Parameters		**Value**				
Number of logistics centre M		**5**				
Number of wood required places N		**3**				
Upper-limit of freight volume W_i		**150**	**140**	**160**	**200**	**170**
Congestion cost parameter	π_{ij}	$i=1$	$i=2$	$i=3$	$i=4$	$i=5$
	$j=1$	13	14	5	6	17
	$j=2$	4.5	5.5	16.5	17.5	18.5
	$j=3$	12.5	11.5	10.5	1.5	2.5
Transportation expense rate	r_{ij}	$i=1$	$i=2$	$i=3$	$i=4$	$i=5$
	$j=1$	0.2	0.3	0.4	0.5	0.6
	$j=2$	0.25	0.35	0.45	0.55	0.65
	$j=3$	0.22	0.32	0.42	0.52	0.62
Transportation distance	d_{ij}	$i=1$	$i=2$	$i=3$	$i=4$	$i=5$
	$j=1$	20	30	40	50	60
	$j=2$	35	25	50	65	70
	$j=3$	40	45	30	20	15
Unit storage cost	μ_{ij}	$i=1$	$i=2$	$i=3$	$i=4$	$i=5$
	$j=1$	0.7	0.73	0.82	0.85	0.89
	$j=2$	0.75	0.78	0.85	0.91	0.95
	$j=3$	0.89	0.85	0.78	0.75	0.67

In this section, we simulate a wood logistics network with 5 logistics centers and 3 wood required places. Assuming all logistics centers and wood required places are inter-connected. Simulation parameters are given in TABLE 1, and assuming $\alpha_{ij} = 0$. The simulation results are shown in Figure 2. It is obviously that we can obtain the optimal timber configuration for the wood logistics network with the minimized transportation cost. As shown in Figure 2, the optimal cargos for required place 3 is larger than required place 2 and required place 1 for logistics center 4 and 5. The optimal minimized utility of each wood required place is given in Figure 3.

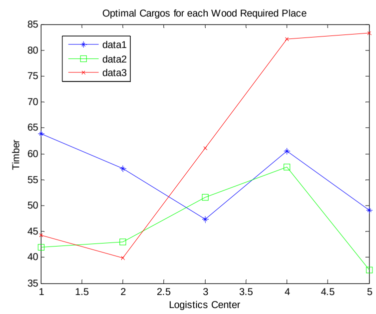

Figure 2 : Optimal timber for every logistics centers

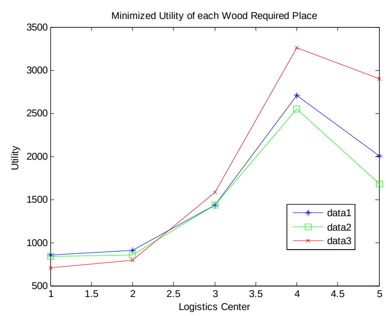

Figure 3 : Minimized utility for every logistics centers

CONCLUSIONS

In this paper, we have discussed the effective wood logistics management based on cost minimization for wood transportation. A utility-based mode is given and it is proved that optimal solutions to the self-optimized wood logistics management can be obtained.

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