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Two Stage Indian Food Grain Supply Chain Network Transportation-Allocation Model

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Abstract: This paper investigates the food grain supply chain, transportation allocation problem of Indian Public Distribution System (PDS). The different activities of Indian food grain supply chain are procurements, storage, movement, transportation and distribution. We have developed a mixed integer nonlinear programming model (MINLP) to minimize the transportation, inventory and operational cost of shipping food grains from the cluster of procurement centers of producing states to the consuming state warehouses. A recently developed chemical reaction optimization (CRO) algorithm is used for testing the model which gives the superior computational performance compared to other metaheuristics.

Keywords: Food grain supply chain, Public Distribution system, Mixed integer non-linear programming problem (MINLP), Chemical reaction optimization.

1. INTRODUCTION

The demand of the food grain is continuously increasing because of increasing the population of the world. To satisfy the increased demand of this population there is a need of more production, more procurement and less wastage of food grains during transit and storage. The food corporation of India (FCI) is the central nodal agency which responsible for handling procurement, storage, movement, transportation and distribution activities of food grains throughout the country. In this work we consider the special case of transportation and distribution of food grains of PDS which is the largest retail system of its type in the world and carried out by FCI. One of the objectives of FCIs is to provide the food grains to needy peoples of the society at reasonable prices. Transportation cost is the major part of this process and to reduce this cost, it needs the effective and efficient movement of food grains from the producing states to consuming states. The movement of food grains is taking place between the producing states and consuming states. Currently, 45% food grain are getting wasted from the post-harvest to distribution stage due to the lack of proper handling, transportation and infrastructure. To reduce this storage and transit losses and to modernize the system of handling, storage and transportation of food grains the Government of India (GOI) has formulated National Policy on Handling, Storage and Transportation of food grains.

The current scenario of food grain transportation in India is having some shortfalls and it requires huge amount of cost for transportation. There is on an average 2 million bags (50 kg per bag) of food grains are transported daily by rail, road, inland waterways etc. from producing states to consuming states which covers the average 1500 km distance (http://www.fci.gov.in/movements/view/5). This movement incurred annual cost of 47.2737 billion INR (CAG, 2013). The stock of food grains in the central pool as on 1st June 2012 is 667.89 LMT excluding the Decentralise procurement (DCP) states procurement against the total of 491.86 LMT FCIs capacity including the state warehousing corporation (SWC) and central warehousing corporation (CWC) capacities (CAG, 2013). This wide gap shows the needs of more storage capacity to cope with the procurement of food grains. In addition to this, key issues of FCIs are shortages of labours, optimal inventory level and handling cost, wastages in transit and warehouses, leakages PDS, carry over charges and demurrage charges of railway rakes etc. The Store in Loose options (SILO) is used to store food grains in bulk form instead of conventional warehouses in bagged form. The silos are made up from concrete or sheet metal structure. In this work we consider the different steel silos located at various part of the country for bulk food grain storage such as Mumbai in Maharashtra, Bangalore in Karnataka, Chennai and Coimbatore in Tamilnadu and Moga in Punjab and Kaithal in Haryana.

To address all these above mentioned constraints we have developed a mixed integer nonlinear programming (MINLP) model considering the deterministic demand and procurement. The movement of food grains from origin node to silos is the first stage and second stage from silos to destination node. The main challenging task of the first stage is the "how much quantity of food grains, from which origin node and where to transport". Furthermore, for food security purpose FCI has to maintain the satisfactory level of operational and buffer stock in a silo.

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The second stage decision is "how much quantity of food grains we can ship from which silo to which warehouse". To maintain the satisfactory and optimal level of inventory in each silo is also a crucial aspect of the problem. It is very difficult to find the exact solutions of this mixed integer nonlinear programming problem. Therefore, chemical reaction optimization algorithm based on mechanisms of chemical reactions has been adopted to solve it. A brief literature of transportation network related problem, metaheuristics such as chemical reaction optimization is presented in section 2 literature review.

2. LITERATURE REVIEW

The enormous literature is available related to the inventory transportation problem, but very few studies have been carried out on the food grain transportation and distribution. Asgari, N. et al (2013) considered the real word case of wheat storage and transportation in Iran, where the objective was to minimize the storage and transportation cost of wheat transported from one warehouse to another. However, they have not considered the rail road flexibility, vehicle capacity and availability constraint. They have considered the preference constraint for filling of wheat into the several warehouses. Recently Maiyar, L. M. et al (2015) developed an effective cost minimization model for Indian food grain supply chain where they have considered the railroad flexibility. But they have not considered the holding cost of food grains in the warehouse and vehicle capacity constraints. Ma, H., et al (2011) studied the shipment consolidation and transportation problem in cross docking distribution networks where they considered trade-offs between transportation, inventory costs and time scheduling requirements. Etemadnia, H., et al (2015) studied the optimal wholesale facility location model within the fruit and vegetable supply chain where they have examined bimodal (land and air transportation) options. Lam, A., & Li, V. O. (2010) developed the chemical reaction inspired metaheuristic called CRO algorithm to solve optimization problems. Choudhary, A., et al (2015) considers the monopolist firm which faces the twin challenge of demand elasticity to emissions and price and reduced net profit. They have used the CRO algorithm to solve the nonlinear programming model. Li, J. Q., & Pan, Q. K. (2012) studied the flexible job-shop scheduling problems with maintenance activity constraints. They have focused on minimization of the maximum completion time (makespan), the total workload of machines and the workload of the critical machine simultaneously. Also, they proposed the effective discrete chemical-reaction optimization (DCRO) algorithm.

In most of the previous transportation related problem they have considered transportation and inventory related costs only, but in this paper we have considered the operational cost of the food grains inside the silos. This cost incurred for the movement of food grains from entry to exit point of the steel silos. The objective is to transport the required amount of food grain quantity to deficit state warehouses with minimum total transportation cost. There is a fixed cost associated with each type of trucks, railway rakes so less number of trucks and rakes should be used to transport the required food grain quantity. The inventory cost of the food grain in the silos is also to be minimized.

3. PROBLEM DESCRIPTION

The procurement of food grains is carried out at various procurement centers (Mandis) located in different part of the district. Clustering of procurement centres is necessary for full utilization of big capacity vehicles. Therefore, in this work we assumed that each origin node is the cluster of procurement centres. The next step is the food grain in bulk form transported between clusters of origin node and silos based on available food grain quantity constraint, truck capacity constraint, and available storage capacity constraint of the silos. The intrastate movement of food grains is mostly done by road and interstate movement through rail. The food grains from several surplus states silos are transported to different deficit states warehouses by rail according to the allocation made by the Government of India on the basis of the requirement of the particular states and off take made by that state in the previous period. The availability of different capacities of railway rakes, inventory and demand of each particular warehouse are the major constraints of this transportation. Indian food grain supply chain consists of four stages. This paper considers the initial two stages of the transportation of food grains. The first stage is intrastate transportation of food grains from the cluster of procurement centres to silos and second stage related to interstate transportation from surplus states silos to deficit states warehouses. Final two stages are intra state distribution up to block level and from block to fair price shops. The details of initial two stage transportation allocation problem are as shown in the Fig. 1.

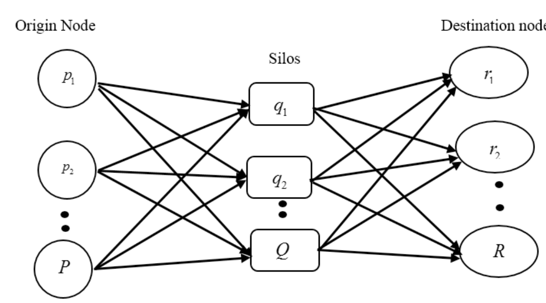

Fig. 1. Two stage food grain supply chain network

4. MODEL FORMULATION

The mixed integer nonlinear programming model is described in this section. Initially, the assumptions of the model and then sets, indices, parameters, decision variables, objective function and finally constraints of the model are discussed.

3.1 Assumptions

1. Each origin node p is a cluster of procurement centers (Mandis)

2. Demand of destination nodes r is deterministic in nature and well known with little variation.

3. No of each type of trucks and rakes are limited.

4. The shipment costs are considered with the travelled distances only not with traveling time among locations.

5. The procured quantity of food grain is sufficient to satisfy the demand of the destination node.

6. The demand of each given destination node r is to be satisfied during that period only.

3.2 Sets

T Set of Time periods

P Set of origin nodes i. e. cluster of procurement centers (mandis)

Q Set of Silos.

R Set of destination nodes

L Set of inbound trucks between origin nodes and silos

M Set of rakes between silos and warehouses.

3.3 Indices

t Time periods

p Origin node

q Silo

r Destination node

l Trucks

m Rakes.

3.4 Parameters

y_p^{lt} Number of l types of trucks available at p during time period t. $(p \in P, l \in L, t \in T)$

z_q^{mt} Number of m types of rakes available at silo q during time period t. $(q \in Q, m \in M, t \in T)$

v_l Capacity of l types of trucks $(l \in L)$

g_m Capacity of m types of rakes

f_l Fixed cost for l types of trucks on arc (p,q) $(l \in L)$

f'_m Fixed cost for m types of rakes on arc (q,r) $(m \in M)$

u_q Inventory holding cost per MT quantity of food grain per time in silo q. $(q \in Q)$

C_{pq} Shipment cost per MT quantity of food grain per km transported by road on arc (p,q) $(p \in P, q \in Q)$

C_{qr} Shipment cost per MT quantity of food grain per km transported by rail on arc (q,r) $(q \in Q, r \in R)$

C_q Operational cost per MT quantity of food grain at silo q. $(q \in Q)$

D_r^t Demand of destination node r for food grain in period t. $(r \in R, t \in T)$

d_{pq} Distance from origin node p to silo q by road. $(p \in P, q \in Q)$

d_{qr} Distance from silo q to destination node r by rail. $(q \in Q, r \in R)$

A_p^t Quantity of food grain available at cluster p during period t. $(p \in P, t \in T)$

B_q Capacity of silo q. $(q \in Q)$

3.5 Binary variables

$$H_{pq}^t \begin{cases} 1 \text{ if origin node } p \text{ is assigned to silo } q \text{ during period } t; \\ 0 \text{ Otherwise.} \end{cases}$$

$$K_{qr}^t \begin{cases} 1 \text{ if silo } q \text{ is assigned to destination node } r \text{ during period } t; \\ 0 \text{ Otherwise.} \end{cases}$$

3.6 Continuous variables

s_{pq}^t Quantity of food grain shipped by truck between p and q during time period t $(p \in P, q \in Q, t \in T)$

$s_{qr}^{'t}$ Quantity of food grain shipped by rake between q and r during time period t $(q \in Q, r \in R, t \in T)$

X_q^t Total quantity of food grain in silo q at time t $(q \in Q, t \in T)$

3.7 Integer variables

n_{pq}^{lt} Number of l types of trucks used on arc (p,q) during time t $(p \in P, q \in Q, l \in L, t \in T)$

$n_{qr}^{'mt}$ Number of m types of rakes used on arc (q,r) during time t $(q \in Q, r \in R, m \in M, t \in T)$

3.8 Objective function

Min Total cost =

$$\sum_{p\in P}\sum_{q\in Q}\sum_{l\in L}\sum_{t\in T}\left[\left(f_l n_{pq}^{lt}\right)+\left(d_{pq}C_{pq}s_{pq}^{t}\right)\right]H_{pq}^{t} +$$

$$\sum_{q\in Q}\sum_{r\in R}\sum_{m\in M}\sum_{t\in T}\left[\left(f_m^{'} n_{qr}^{'mt}\right)+\left(d_{qr}C_{qr}s_{qr}^{'t}\right)\right]K_{qr}^{t} +$$

$$\sum_{t\in T}\left[\sum_{p\in P}\sum_{q\in Q}s_{pq}^{t}+\sum_{q\in Q}\sum_{r\in R}s_{qr}^{'t}\right]C_q+\sum_{q\in Q}\sum_{t\in T}u_q X_q^t$$

Subject to

$$\sum_{q\in Q}s_{pq}^{t}H_{pq}^{t}\le A_p^t \qquad \forall p,\forall t \qquad (1)$$

$$\sum_{r\in R}s_{qr}^{'t}K_{qr}^{t}\le X_q^t \qquad \forall q,\forall t \qquad (2)$$

$$\sum_{q\in Q}s_{qr}^{'t}K_{qr}^{t}= D_r^t \qquad \forall r,\forall t \qquad (3)$$

$$X_q^{t-1}+\sum_{p\in P}s_{pq}^{t}H_{pq}^{t}-\sum_{r\in R}s_{qr}^{'t}K_{qr}^{t}\le B_q \qquad \forall q,\forall t \qquad (4)$$

$$X_q^{t-1}+\sum_{p\in P}s_{pq}^{t}H_{pq}^{t}-\sum_{r\in R}s_{qr}^{'t}K_{qr}^{t}= X_q^t \qquad \forall q,\forall t \qquad (5)$$

$$X_q^{t\in 1}=0 \qquad \forall q,\forall t \qquad (6)$$

$$\sum_{q\in Q}s_{pq}^{t}H_{pq}^{t}\le \sum_{q\in Q}\sum_{l\in L}n_{pq}^{lt}v_l \qquad \forall p,\forall t \qquad (7)$$

$$\sum_{r\in R}s_{qr}^{'t}K_{qr}^{t}\le \sum_{r\in R}\sum_{m\in M}n_{qr}^{'mt}g_m \qquad \forall q,\forall t \qquad (8)$$

$$H_{pq}^t, K_{qr}^t=\{0,1\} \qquad \forall p,\forall q,\forall r,\forall t \qquad (9)$$

$$s_{pq}^t, s_{qr}^{'t}, X_q^t \ge 0 \qquad \forall p,\forall q,\forall r,\forall t \qquad (10)$$

$$n_{pq}^{lt}, r_{qr}^{'mt}\in N_0 \text{ where } N_0=\{0,1,2,3....\} \qquad \forall p,\forall q,\forall r,\forall l,\forall m,\forall t \qquad (11)$$

The objective function is to minimize the total cost which includes four terms. The first term represents the fixed and variable cost of food grains transported by road between origin node and assigned silos. The second term depicts the fixed and variable cost of food grains shipped through rail between silos and assigned destination node. The next term is related to the operational cost of the food grains inside the silos. The last term illustrates the food grain holding cost in silos. Constraints (1) and (2) are the supply constraint of the origin node and silos, respectively. Constraint (3) shows that demand of each given destination node should be satisfied. The capacity constraint of the silos is represented by the equation (4). The constraint (5) ensures the inventory flow balance at the silos. Initial inventory of each silo is zero indicates the constraint (6). Constraint (7) and (8) ensures trucks and rakes capacity constraint, correspondingly. The last three constraints (9), (10) and (11) describes the binary, non negativity and integer constraints, respectively.

5. SOLUTION METHODOLOGY

The brief introduction of the recently developed chemical reaction optimization algorithm is given in this section.

4.1 Chemical reaction optimization (CRO):

The CRO is the variable population based metaheuristic and inspired by the mechanism of chemical reactions. This recently developed optimization method has become effective to tackle many real world NP hard problems. Because of that, most of the researchers are now focusing on this algorithm to solve their optimization problems. Xu, J., et al (2011) proposed the several versions of the CRO algorithm for solving the grid scheduling problem. They have considered the reliability of resources as a third objective, in addition to the makespan and flow time. Xu, Y., et al (2013) examined the scheduling problem of Directed Acyclic Graph (DAG) jobs in heterogeneous computing systems and they developed a Double Molecular Structure-based Chemical Reaction Optimization (DMSCRO) method. Li, J. Q., & Pan, Q. K. (2013) used the hybrid CRO for flexible job shop scheduling problem where they considered the fuzzy processing time and flexible maintenance activities. Recently, Xu, Y., et al (2015) studied the directed acyclic graph (DAG) based task scheduling problem where they proposed the HCRO for solving it. Basically, CRO is based on the two laws of the thermodynamics. First one is conservation of energy and the second states that the entropy of the system always tends to increase. The unstable molecule with high potential energy and low entropy tries to attain the stable state by converting the potential energy into kinetic energy and increasing the entropy. This conversion will happen when two molecules collide with each other. The four types of elementary reactions, e.g. decomposition, on wall ineffective collision (Uni-molecular) and Synthesis, Inter-molecular ineffective collision (Inter-molecular) are the result of this collision. The one reaction from these four can be selected in each iteration. The unstable molecules will step by step attain the stable state and CRO resembles this phenomena for finding the global optima in the solution space. The local search (intensification) is carried out by the two ineffective collision (on wall and inter molecule) and diversification will take place because of decomposition and synthesis. The combination of intensification and diversification will help in finding the global optima in the solution space.

CRO gives the benefits of both genetic algorithm (GA) and simulated annealing (SA). The crossover and mutation operator of the GA is strongly related with the decomposition and synthesis reactions of the CRO. The CRO will perform same as GA when the decomposition and synthesis reactions selected in the algorithm. This algorithm will give similar results like SA when the least number of molecules used. Distribution of energy among the molecules and transfer of energy from one form to another are the most distinguishable features of the CRO. If this algorithm applies to the right type of problem, then it will outperform the most widely used metaheuristics. Furthermore, CRO gives the superior computational performance while solving the NP hard problems such as quadratic assignment problem, resource-constrained project scheduling problem and task scheduling in grid computing. All these above mentioned features make the CRO unique compare to the other metaheuristic and it can be useful to solve the real life NP hard problems. So we have implemented this algorithm to solve our MINLP model.

6. RESULTS AND DISCUSSION

A simple case of 3 origin nodes, 2 silos, 3 destination nodes and 2 time periods is considered for testing the developed model. The procured food grain quantity and demand are given in the table 1. We have considered 3 different capacities of trucks for transporting the food grains from origin node to silos and 3 different capacities of rakes for silos to destination node. The CRO is used to find out the optimal quantity of food grains transported from origin node to silos and from silos to destination node to satisfy the demand of destination node. We have carried out the experiments on the simulated data set. The food grains shipped from origin node to silos and from silos to destination node in two time periods are presented in the table 2 and 3, respectively. The number of each types of trucks used between origin nodes and silos during first and second period are shown in the table 4 and 5, respectively. Table 6 and 7 demonstrates the number of each types of rakes used from silos to destination node in first and second time periods. In addition to this, table 8 depicts the inventory remaining in each silo.

Table 1. Procured quantity and demand in tons

Time period (t)	Procured Quantity (A_p^t)			Demand (D_r^t)		
	$A_{p_1}^t$	$A_{p_2}^t$	$A_{p_3}^t$	$D_{r_1}^t$	$D_{r_2}^t$	$D_{r_3}^t$
1	200	230	350	80	180	120
2	300	210	260	130	150	90

Table 2. Quantity moved from origin node to silos in tons

		Silos			
		$t=1$		$t=2$	
		q_1	q_2	q_1	q_2
Origin node	p_1	0	150	125	75
	p_2	125	75	125	75
	p_3	125	75	0	150

Table 3. Quantity shipped from silos to destination nodes in tons

		Destination node					
		$t=1$			$t=2$		
		r_1	r_2	r_3	r_1	r_2	r_3
Silos	q_1	0	90	60	65	75	45
	q_2	80	90	60	65	75	45

Table 4. Number of l types of trucks used between origin nodes and silos when $t=1$

$t=1$		Silos					
		l_1		l_2		l_3	
		q_1	q_2	q_1	q_2	q_1	q_2
Origin node	p_1	0	2	0	5	0	6
	p_2	5	1	2	5	3	0
	p_3	5	1	3	2	2	4

Table 5. Number of l types of trucks used between origin nodes and silos when $t=2$

$t=2$		Silos					
		l_1		l_2		l_3	
		q_1	q_2	q_1	q_2	q_1	q_2
Origin node	p_1	6	0	3	4	1	3
	p_2	2	2	1	2	9	3
	p_3	0	4	0	3	0	6

Table 6. Number of m types of rakes used between silos and destination nodes when $t=1$

$t=1$		Destination node								
		m_1			m_2			m_3		
		r_1	r_2	r_3	r_1	r_2	r_3	r_1	r_2	r_3
Silos	q_1	0	1	0	0	0	2	0	2	0
	q_2	0	0	0	1	3	2	2	0	0

Table 7. Number of m types of rakes used between silos and destination nodes when $t=2$

$t=2$		Destination node								
		m_1			m_2			m_3		
		r_1	r_2	r_3	r_1	r_2	r_3	r_1	r_2	r_3
Silos	q_1	0	2	1	2	0	1	1	1	0
	q_2	0	1	1	2	2	1	1	0	0

Table 8. Inventory at each silos in tons

		$t=1$	$t=2$
Silos	q_1	100	165
	q_2	70	185

The total cost of the objective function is 1889175 in INR. The result also shows the allocation of the origin nodes to silos and silos to destination nodes. We have tested this model on the small case problem, but if the problem size increases, it will be complex to find out all these above mentioned entities values. The least variation between actual quantities and actual no of vehicles moved are neglected in this calculation.

7. CONCLUSION AND FUTURE SCOPE

The developed MINLP model tries to minimize total cost which includes transportation, inventory and operational cost of the food grains. The issues with operational cost have not been addressed in the previous literatures. Therefore, we include it in this study. The newly developed CRO metaheuristic which inspired from the chemical reactions of the molecules has been employed as a solution approach. The presented results show the efficacy of the CRO for solving this type of problems with superior computational performance. Validation of the model has been performed using the simple test case problem. For the future scope, the model will be tested on the large size problem instances and can be compared with any other metaheuristic results. The work presented here can be extended to other perishable items and similar situation of the problem. Moreover, multi food grain, railroad flexibility from silos to destination nodes and sustainability would be the other extensions.

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