Computers & Industrial Engineering 110 (2017) 379–394

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

A multi-period inventory transportation model for tactical planning of food grain supply chain

D.G. Mogale [a], Alexandre Dolgui [b], Rishabh Kandhway [a], Sri Krishna Kumar [a], Manoj Kumar Tiwari [a,*]

[a] Department of Industrial and Systems Engineering, Indian Institute of Technology Kharagpur, Kharagpur 721 302, West Bengal, India
[b] IMT Atlantique, LS2N, UMR CNRS 6004, B.P. 20722-44307 Nantes Cedex 3, France

ARTICLE INFO

Article history:
Received 7 March 2017
Received in revised form 5 June 2017
Accepted 6 June 2017
Available online 9 June 2017

Keywords:
Distribution system
Supply chain management
Inventory
Transportation
Mixed integer non-linear programming
Ant colony optimization

ABSTRACT

The food grain supply chain problem of the Public Distribution System (PDS) of India is addressed in this paper to satisfy the demand of the deficit Indian states. The problem involves the transportation of bulk food grain by capacitated vehicles from surplus states to deficit states through silo storage. A mixed integer non-linear programming (MINLP) model is formulated which seeks to minimize the overall cost including bulk food grain shipment, storage, and operational cost. The model incorporates the novel vehicle preference constraints along with the seasonal procurement, silo storage, vehicle capacity and demand satisfaction restrictions. The management of Indian food grain supply chain network is more intricate and difficult issue due to many uncertain interventions and its chaotic nature. To tackle the aforementioned problem an effective meta-heuristic which based on the strategy of sorting elite ants and pheromone trail updating called Improved Max-Min Ant System (IMMAS) is proposed. The solutions obtained through IMMAS is validated by implementing the Max-Min Ant System (MMAS). A sensitivity analysis has been performed to visualize the effect of model parameters on the solution quality. Finally, the statistical analysis is carried out for confirming the superiority of the proposed algorithm over the other.

1. Introduction

India is the second largest food grains (wheat and rice) producer in the world after China. Despite this fact, India is still facing the challenge of feeding the high-quality, nutritious and safe food to more than one billion peoples in the country (Mukherjee, Himanshu, Namit, & Joshua, 2013). India is ranked at 80th position out of 104 countries in the Global Hunger Index (GHI) and lagging the neighboring country such as Nepal, Sri Lanka and China (Von Grebmer, Bernstein, Prasai, Yin, & Yohannes, 2015). In India, every year around 25–30% of agricultural production gets wasted due to the improper handling and storage, poor logistics, inadequate storage and lack of transportation infrastructure (Sachan & Datta, 2005). As per the Food and Agriculture Organization (FAO) of the United Nations estimation, out of total food produced for human consumption, 32% of the food by weight was wasted across the entire food supply chain in 2009, equivalent to around 1.3 billion tons (FAO, 2011). According to The World Bank Annual Report (1999), post-harvest losses in India amount to 12–16 million metric tons of food grains each year, an amount that the World Bank stipulates could feed one-third of India's poor. The monetary value of these losses amounts to more than Rs 50,000 crores (7515.689 million US dollars) per year (Naik & Kaushik, 2011; Singh, 2010). The improper transportation planning, untimely deliveries, mismatched demand-produce scenario, inadequate infrastructure and highly inefficient supply chain are the primarily causes behind this (Maiyar & Thakkar, 2017; Parwez, 2014). In the past few decades, the major concern of developing countries was on the increasing the food production to feed the growing population and the advanced agricultural production technologies have helped to increase the production, but they have not given the proper attention towards the reduction of losses.

The targeted Public Distribution System (PDS) is the national food security system of India, which provides food grains to poor people of the society at a subsidized rate. The procurement, storage, movement and distribution to final consumers are the major stages of the food grain supply chain. The Food Corporation of India (FCI) is the central nodal agency which handles all these activities as shown in Fig. 1. The various states in India are categorized into producing and consuming states based on production quantity of food grains. The food grain is procured under two scheme, i.e. centralized and decentralized procurement scheme. In a centralized system, FCI and several State Government Agencies (SGAs) procure

* Corresponding author.
E-mail addresses: mkt09@hotmail.com, mktres09@gmail.com (M.K. Tiwari).

http://dx.doi.org/10.1016/j.cie.2017.06.008
0360-8352/

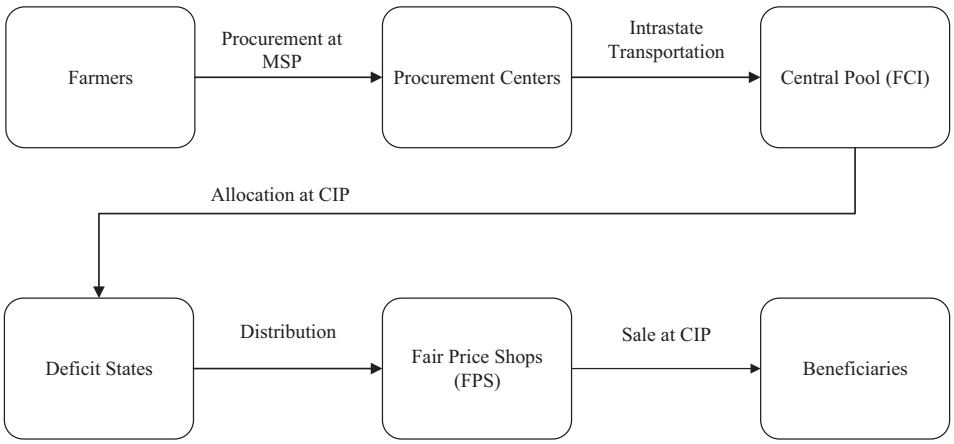

Fig. 1. PDS activities.

the food grain from the farmers in procurement centers, located in different parts of states, at minimum support price (MSP). Next, this procured food grain is transported to FCIs central warehouses for storage. The Government of India (GOI) makes the annual allocation at a uniform central issue price (CIP) to each consuming state and Union territories based on the demand of the state and off-take in the previous period. The consuming state takes care of the distribution of food grains from state depot to the final consumer. Primarily, the interstate movement of food grain from producing state to consuming state depot is carried out by rail mode and intrastate movement through road. Under decentralized procurement (DCP), SGAs procures, store and distribute food grains to beneficiaries through PDS on behalf of the GOI.

Presently, FCI is facing numerous major issues and challenges related to food grain storage and transportation. FCI yearly transports around 40 to 50 million tons of food grains through rail, road and waterways across the country which incurred the average expenditure of 47.2737 billion (CAG, 2013). The key issues of food grain supply chain include a huge amount of transportation and handling cost, underutilization of existing storage facilities, leakages in PDS, manpower shortages, vague buffer stock norms, unavailability of a sufficient number of vehicles, manual loading and unloading of gunny bags and lack of modern storage facilities. FCI has to maintain the operational and buffer stock of food grains in deficit states for food security purpose. Currently, PDS is having a large network of 5.13 lakh Fair Price Shops (FPS) in throughout the country which becomes a largest retail system in the world. To handle all these real time major issues and challenges of Indian PDS, FCI needs the effective storage and movement plan of food grains with time.

In this paper, we have examined the issue of bulk food grain transportation between producing and consuming states along with silo storage considering operational (handling) cost inside the silos. Food grain supply chain has been divided into four stages as described follows.

1. Intrastate food grain transportation from procurement centers to silos in surplus states.
2. Interstate shipment from surplus state silos to deficit state silos.
3. The grain shipment from deficit state silos up to block level and
4. The food grain shipment from block level to fair price shops.

In this study, we consider major wheat producing and consuming states like Punjab, Haryana, Madhya Pradesh, Uttar Pradesh, Rajasthan and Maharashtra, Tamilnadu, Karnataka, West Bengal, respectively.

The food grain transportation and storage problem is complex with below mentioned numerous constraints and specificities.

The FCI has to take the efficient decisions about "from which surplus nodes to which surplus state silos and when to transport the food grains" in order to minimize the food grain supply chain cost. The operational and inventory holding cost of food grain at the surplus state silos, availability of food grain at surplus nodes, silo storage capacity, the demand of particular deficit state and availability of different capacitated vehicles are considered.

The next important goal is to minimize the total numbers of vehicles required for food grain transportation. The total time requires for movement of food grains is influenced by the different capacitated vehicles because if high capacity vehicles are utilized then it transports the food grains in fewer numbers of the trip than low capacitated vehicles. However, in real time scenario sufficient numbers of each type of capacitated vehicles may not be available during the particular time period. In general, we can say that if high capacitated vehicles are given the first priority than low capacitated vehicles, then the cost and time require for movement will be minimized. Thus, owing to all these vehicles related issues the novel vehicle preference constraints are formulated for shipping the food grain, which has not been addressed in most of the previous transportation related literature.

Two main contributions of this paper are as follows. First, a novel MINLP mathematical model is formulated to minimize the food grain supply chain cost in India. It considers simultaneously the seasonal procurement, heterogeneous vehicles and their fixed costs, inventory and operational costs of food grain, specific vehicle preference constraints, capacitated silos, intermodal transportation and a definite planning horizon. Second, we propose a variant of MMAS algorithm called IMMAS to solve the MINLP model in a reasonable computational time.

Following this introduction, in Section 2 some related works are described in perspective of food supply chain transportation problems. Conventional heuristics and metaheuristics used as solution approaches are reported. Section 3 describes the problem background of the Indian food grain supply chain. Section 4 presents the MINLP mathematical formulation including the objective function and constraints. Section 5 describes the proposed IMMAS algorithm for solving the model. Section 6 is devoted to the extensive analysis of the model results and discussion. Finally, conclusions are given in Section 7 which includes some recommendation for future research.

2. Related work

The food supply chain transportation problem is not new and many studies have been carried out before. For better understanding, the below presentation of the existing results is divided into