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An MINLP model to support the movement and storage decisions of the Indian food grain supply chain

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ABSTRACT

This paper addresses the novel three stage food grain distribution problem of Public Distribution System (PDS) in India which comprises of farmers, procurement centers, base silos and field silos. The Indian food grain supply chain consists of various activities such as procurement, storage, transportation and distribution of food grain. In order to curb transportation and storage losses of food grain, the Food Corporation of India (FCI) is moving towards the modernized bulk food grain supply chain system. This paper develops a Mixed Integer Non-Linear Programming (MINLP) model for planning the movement and storage of food grain from surplus states to deficit states considering the seasonal procurement, silo capacity, demand satisfaction and vehicle capacity constraints. The objective function of the model seeks to minimize the bulk food grain transportation, inventory holding, and operational cost. Therein, shipment cost contains the fixed and variable cost, inventory holding and operational cost considered at the procurement centers and base silos. The developed mathematical model is computationally complex in nature due to nonlinearity, the presence of numerous binary and integer variables along with a huge number of constraints, thus, it is very difficult to solve it using exact methods. Therefore, recently developed, Hybrid Particle-Chemical Reaction Optimization (HP-CRO) algorithm has been employed to solve the MINLP model. Different problem instances with growing complexities are solved using HP-CRO and the results are compared with basic Chemical Reaction Optimization (CRO) and Particle Swarm Optimization (PSO) algorithms. The results of computational experiments illustrate that the HP-CRO algorithm is competent enough to obtain the better quality solutions within reasonable computational time.

1. Introduction

Recently, the Government of India (GOI) has implemented the National Food Security Act (NFSA), 2013 across the country including all states and Union Territories for providing the food and nutritional security. This act is the key initiative for ensuring the food security which can be defined as economic access to the adequate quality food. Under this act, the targeted beneficiaries can get the highly subsidized food grains, i.e. wheat, rice, and cereals through PDS. The NFSA includes the 75% rural population and 50% urban population which makes the overall coverage of two third (67%) population of India (http://dfpd.nic.in/nfsa-act.htm). In order to provide the food grains to the large volume of the population, India has to increase its production, procurement and reduce the losses during transportation and storage. The major food grain supply chain related activities including procurement, storage, movement and distribution are taken care by the Central nodal agency called FCI. The procurement is carried out in the procurement centers of surplus states by FCI and State Government Agencies (SGAs) at the rate of Minimum Support Price (MSP). Normally, the different food grains procured in different seasons such as in Rabi season (April to June) wheat is procured and in Kharif season (October to February) Rice procures. FCI takes over the procured stock of food grain from SGAs and stores in its own warehouses of producing states. Next, GOI allocates the food grains to various deficit states and Union Territories based on their demand and offtake of the previous period. In consuming states, food grain stock is moved from regional warehouses to block level and block level to Fair Price Shops (FPS). Generally, FCI prefers the road mode for intra-state transportation and rail mode for inter-state transportation. All these major food grain supply chain activities are depicted in Fig. 1.

The Indian PDS is world's largest distribution system and its management is a complex issue due to the involvement of many entities such as FCI, SGAs, Railways, transporters and private contractors. In the

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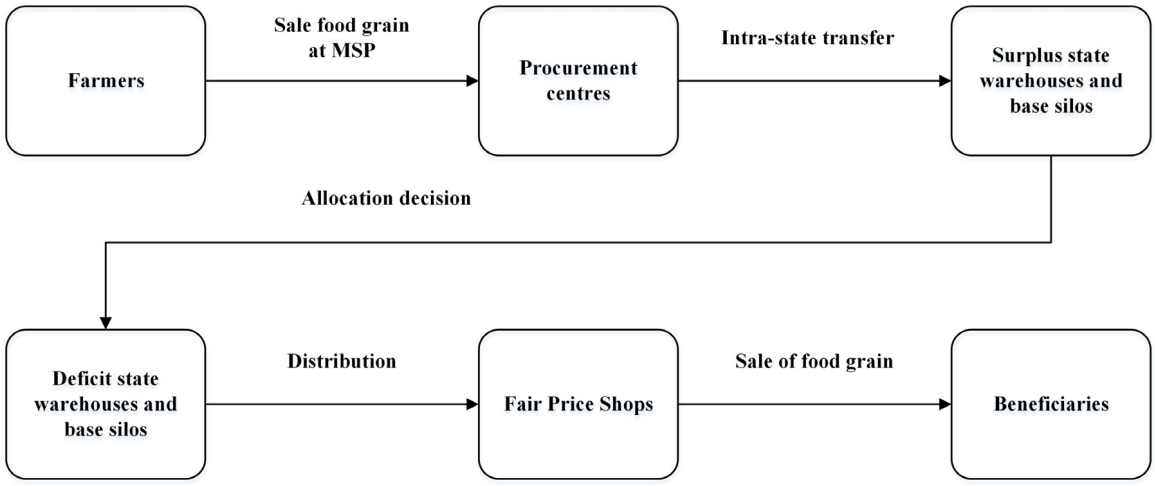

Fig. 1. Major activities of FCI.

conventional method, food grain is stored in godowns and transported using the gunny bags which has several flaws. The first and paramount important shortcoming is the huge amount of transportation and storage cost. FCI transports the 40 to 50 million tons of food grains across the country in a year through rail, road and waterways which incurred the average expenditure of 47.2737 billion (Comptroller and General of India (CAG), 2013). The FCIs total storage capacity including hired one was 336.04 Lakh Metric Tonne (LMT) as against the central pool stock of 667.89 LMT at the end of the March 2012 thus leaving a huge gap of 331.85 LMT. Next, the inadequate storage management practices and unclear norms of operational and buffer stock maintenance of deficit state leads to increase of food grains holding cost. In addition to the above inadequacies, FCI is also facing the problem of food grain losses which mainly occurred from post-harvest to distribution stage of food grain supply chain, i.e. during storage and transit. The shortages of labors and their huge salaries (handling cost), shortages of different capacitated vehicles (rakes and trucks), demurrage payment, carry over charges, and loading and unloading time are some of the other major challenges.

To tackle the aforementioned challenges, GOI is moving towards the modernized food grain supply chain system of bulk grain handling, transportation and storage. In this modernized system, food grain (wheat) is transported in bulk form using the truck as well as specially designed wagons and stored in steel silos. The silos located in the surplus and deficit states are known as Base silo and Field silo, respectively. Proper planning and coordination among all the entities of the food grain supply chain network can reduce the transportation as well as inventory cost and helps to take the various timely decisions such as "how much quantity to be transferred from which origin node to which base silo and from which base silo to which field silo". Similarly, the determination of each type of capacitated vehicles used for shipment between different entities is also the crucial aspect of food grain supply chain problem because the sufficient availability of capacitated vehicles helps for quick transfer of food grain from producing states to consuming states. Furthermore, FCI has to maintain the optimal level of operational and buffer stock in each silo for food security purpose. This paper considers the initial three stages of food grain supply chain network, including the origin nodes (farmers), procurement centers, base silos and field silos. An MINLP model is formulated after the critical analysis of Indian food grain supply chain network and various reports on PDS. The solution of the model will be helpful to FCI for taking the timely intra-state as well as inter-state movement and storage-related decisions. This paper extends the work carried out by the Mogale, Kumar, and Tiwari (2016) and differ in following aspects. Here, 1. Three stage food grain distribution network is considered where food grain can be shipped from an origin node to procurement centers or base silos, 2. Inventory and operational costs considered at procurement centers and base silos, 3. Included the new vehicle capacity related constraints, 4. Different problem instances of the formulated MINLP model are solved using the recently developed HP-CRO algorithm and attained results compared with the CRO and PSO results. 5. Furthermore, the convergence behavior and movement along with storage activities of few selected instances are analyzed in detailed.

The remaining article is organized as follows. Section 2 presents the critical review of related work. In Section 3, the detailed delineation of considered problem is provided. The mathematical model with notations, objective function and constraints are illustrated in Section 4. Section 5 discusses the solution approach employed for solving the mathematical model. Section 6 depicts the results and analysis of computational experiments. Conclusion and future scope of the study is given in Section 7.

2. Related work

The supply chain distribution problem in the context of manufacturing industries has been widely addressed by several researchers in the past. The existing relevant works focusing on food supply chain related problems including inventory-transportation, post-harvest loss minimization, food distribution system and their solution methodologies, review papers along with advanced control techniques in agricultural systems have been described in this section. Recently, the real-world optimization problem of wheat transportation and storage in Iran has been effectively addressed by Asgari, Farahani, Rashidi-bajgan, and Sajadieh (2013) by formulating the problem as a linear integer programming (LIP) model. The LINGO optimization software was used to solve LIP model and obtained results compared with the Genetic Algorithm (GA) which takes reasonable computational time for solving large size problems. Authors have not taken into account the different capacity and availability of transportation vehicles. An MINLP model has been formulated considering rail road flexibility by Maiyar, Thakkar, Awasthi, and Tiwari (2015) to optimize food grain transportation problem of Indian PDS. The food grain storage cost and capacity constraints of transportation vehicles are absent in their model. In the same domain of Indian food grain supply chain, Mogale et al. (2016) developed the two stage MINLP model for efficient transportation and storage of food grain from surplus states to deficit states. They have tested the model on single small size problem instance and results were not compared with other evolutionary algorithms. A deterministic mathematical model was proposed by Reis and Leal (2015) for optimization of tactical decisions of soybean supply chain