Computers & Industrial Engineering 110 (2017) 30–42

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

A combined tactical and operational deterministic food grain transportation model: Particle swarm based optimization approach

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ARTICLE INFO

Article history:
Received 16 June 2016
Received in revised form 25 February 2017
Accepted 19 May 2017
Available online 22 May 2017

Keywords:
Deterministic demand
MINLP
Food grain transportation
Supply network optimization
Swarm intelligence
PSOCP

ABSTRACT

This paper proposes a combined tactical and operational two stage food grain transportation model with linear formulation in the first stage and a mixed-integer non-linear problem (MINLP) in the second stage taking the case of India. Transportation cost is minimized in both stages to fulfil a deterministic demand. First and the second stages correspond to the movement of food grains in between state and central level warehouses respectively. A novel k-parameter based method of constraint handling has been proposed. Further, the two stage MINLP formulation newly incorporates vehicle capacity constraints and proposes a generic metric for measuring vehicle utilization. First stage is solved by CPLEX and for the second stage, two population based random search techniques: Particle swarm optimization-composite particle (PSOCP) and PSO, have been employed. Experimentations on 10 different problem sets reveal that PSOCP performs marginally better than PSO with lesser standard deviation of global fitness and better solution quality with slightly higher CPU time. Later, sensitivity analysis is conducted on all ten problem sets and a decision support framework is proposed to assist potential stakeholders.

1. Introduction

Facts reveal that more than 50% of the food grains are wasted (CAG report, 2013) in India annually, the reasons for which are mainly related to improper transportation planning, uneconomic utilization of resources, untimely deliveries, improper rolling stock management and mismatched demand-produce scenario. Effective transportation management helps to minimize wastages and improve the overall cost across the supply chain especially in developing economies (Song, Wang, & Fisher 2014). Integrating the strategic, tactical and operational levels of planning contributes to improved reliability, flexibility and sustainability (Steadieseifi, Dellaert, Nuijten, Van Woensel, & Raoufi, 2014). The combined tactical and operational transportation planning problem addressed in this paper extends the work done by Maiyar, Thakkar, Awasthi, and Tiwari (2015) while newly incorporating vehicle capacity constraints and proposes a generic metric for measuring overall vehicle utilization.

The intra-state transportation problem addressed in this paper has been formulated in two stages: Intra-state state agency transportation stage and Intra-state FCI transportation stage. The first stage constitutes a linear model minimizing the transportation costs subject to demand, supply and warehouse capacity constraints. The resulting unmet demands from the Stage 1 problem are provided as input to the Stage 2. The second stage is formulated as non-linear mixed integer model that minimizes the transportation cost subject to several contextual operational constraints in addition to the demand, supply and vehicle capacity constraints.

This paragraph briefs the contributions from this paper to literature. Firstly a novel mathematical model to represent the food grain transportation system has been developed and validated. Secondly an attempt to integrate the tactical and operational planning phases has been made by way of introducing vehicle capacity and mode selection constraints in the two-stage formulation along with tactical flow decisions to be made. A generic metric to measure the vehicle utilization has been introduced. Thirdly the concept of particle swarm optimization – composite particle along with traditional PSO has been translated and applied to food grain transportation domain. Finally, a brief sensitivity analysis has been conducted to understand the responsiveness of the proposed model and methodology.

The remainder of the paper is organized as follows. The second section gives a brief overview of literature studied. Section 3 describes the problem environment. The mathematical model with objective function and constraints is described in Section 4. Section 5 illustrates the importance and implementation of PSO and PSOCP for the proposed problem. The description of datasets and plan of computational experiments are discussed in Section 6. Section 7 discusses results along with sensitivity analysis. A decision

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http://dx.doi.org/10.1016/j.cie.2017.05.023
0360-8352/

support framework is presented in Section 8, before concluding the work in the ninth section.

2. Literature review

In the context of supply chain, transportation problems dealing with food grain commodities is limited in literature. Asgari, Farahani, Rashidi-Bajgan, and Sajadieh (2013) minimize transportation and storage for a case of wheat production in Iran. Hong and An (2008) modelled a Beijing based grain supply chain and reasons for inefficiency in supply chain transportation were discussed. A functional clustering based technique was used by Ng and Lam (2014) to optimize supply networks and ensure proper allocation of industrial resources. A detailed review of planning models in agri-food supply chain context can be seen in Ahumada and Villalobos (2009). The same authors in the subsequent years (Ahumada, Rene Villalobos, & Nicholas Mason, 2012; Ahumada & Villalobos, 2011) explored modelling intricacies while dealing with harvest and distribution of perishable agricultural products. Thakur, Wang, and Hurburgh (2010) focussed on bulk grain operations and suggested useful strategies to improve handling by balancing traceability and cost aspects. A recent work in bulk grain movement with major focus on silo operations was conducted by Mogale, Krishna, Pedro, Márquez, and Kumar (2017). Etemadnia, Goetz, Canning, and Tavallali (2015) developed a mathematical model for fruit and vegetable supply chain considering travel distance, hub capacity and transportation cost. Strategic and tactical operations for crude oil supply chain were captured by Sahebi, Nickel, and Ashayeri (2014). A Brazil based Soyabean supply chain was studied by Reis and Leal (2015) and investigated the importance of temporal and spatial decisions in the presence of deterministic demand. Gunnarsson, Rönnqvist, and Lundgren (2004) developed a heuristic to solve large mixed integer linear programming model in an attempt to address transportation issues emerging in moving forest fuel. Availability of multiple transport modes gives rise to cost and priority concerns with respect to mode selection while dealing with multi-modal and intermodal transportation problems (Steadieseifi et al., 2014). A mode selection problem with vehicle capacity and lead time constraints was dealt by Eskigun et al. (2005).

In network optimization problems, the focus of strategic planning models is to design a superficial network structure with decisions pertaining to continuous or discrete flows, binary node-to-node allocations, and nodal capacities. (Ahn, Lee, Lee, & Han, 2015; Elhedhli & Gzara, 2008). At the tactical level, ensuring optimal allocation and utilization of vehicle resources, proper facility planning and effective rolling stock management are important (Yang, Li, Gao, & Li 2012; De Meyer, Cattrysse, & Van Orshoven 2015; Fodstad, Midthun, & Tomasgard 2015). Sahebi et al. (2014) portrayed a review on different strategic and tactical decisions relevant to crude-oil supply chains. As we approach operational planning, problems pertaining to choice of transport mode, addressing delivery delay and loading/unloading operations, scheduling, timetabling, dispatching problems and multi-period problems are well recognized in literature (D'Ariano, Pacciarelli, & Pranzo 2007; Upadhyay & Bolia, 2014; Goetschalckx, Vidal, Dogan, 2002). A critical review on all three levels of planning is found in Schmidt and Wilhelm (2000).

It can be seen from the literature presented that transportation related issues have been addressed less significantly in the context of food grain supply chain. Further in this area, an integrated tactical and operational models to imitate the practical scenario of operations are scarce. Hence, in this paper it is attempted to address this gap by introducing certain industrially relevant novel operational constraints to achieve minimized cost of transportation while deciding on warehouse level movement quantities and binary rail-road allocations in food grain context. The detailed description of the problem environment, solution methodology adapted, experiments, results and conclusions drawn are presented in the subsequent sections.

3. Problem description

The tactical and operational transportation network design problem studied in this paper deals mainly with two players: Food Corporation of India (FCI) and the state. In every state, there are a finite number of regions and in each region there are finite number of warehouses. Food grains are stored in two types of warehouses: state owned warehouses and FCI owned warehouses. A state tries to satisfy the demand of its own warehouses as the first priority from the available stock at state warehouses. Fig. 1 shows a bird's eye view of the problem environment. Stage1 deals with the movement between state warehouses and the transportation is carried out by only road. Later, the region wise unsatisfied demand, if any, is communicated to the FCI who further plan the intra FCI movement to fulfil the unmet demand of food grains in the stage 2. A vehicle is also allowed to travel from warehouse of one region to a warehouse of another region if there exists a route. It is illustrated in Fig. 1 shown by the arrow going from region 3 to region 1. All the directed arrows in the figure represent single mode of transport movement between the warehouses. In this paper, FCI is allowed to use both rail and road modes of transport to facilitate the food grain shipments, however not simultaneously. The detailed description of the mathematical model developed with objective function and constraints are presented in the next section.

4. Mathematical model

The mathematical formulation of the two stage problem is described in this section. The first stage minimizes the total cost of transportation of food grains between the state warehouses and the second stage minimizes the total cost of transportation of food grains between the FCI warehouses. Considering the complexity in modelling the real life scenario following six assumptions are made

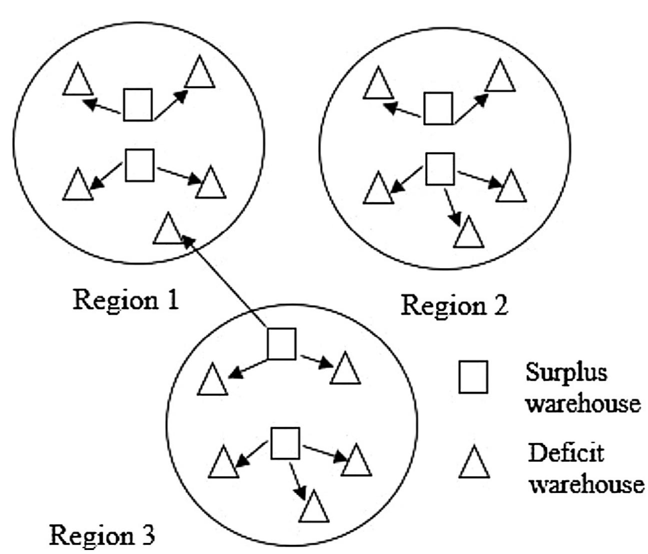

Fig. 1. Bird's eye view of the problem environment.