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Optimization of inventory policies of food grain distribution stage in public distribution system

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Abstract

Purpose – The purpose of this paper is to model the distribution stage of the public distribution system (PDS) and optimize the inventory policy during this stage of the PDS to address some of the inefficiencies present in the system. This study models this supply chain as a multistage supply chain consisting of storage depots, issue centers, fair price shops and card holders.

Design/methodology/approach – A two-stage modeling approach is used to model the distribution stage in the PDS. In the first stage, the authors developed a simulation model for periodic review-based stock policy with appropriate assumptions. This helped minimize the total supply chain cost (TSCC). The TSCC consists of three cost elements, namely, ordering cost, holding cost and shortage cost. These three cost elements, in turn, depend on inventory policy parameters, such as review periods and base stock levels, at various echelons. In the second stage, a Genetic Algorithm based optimization approach was used.

Findings – A set of optimal policy parameters was identified. It is observed that base stock levels at issue centers are higher as compared to those in the FPS and the TSCC is less in scenario, when backorder cost is equal to the holding cost.

Practical implications – Present study will be useful to policy makers in improving PDS performance. This optimization of inventory policies helps actors in the PDS supply chain to choose appropriate policy parameters in the present inventory policy so as to reduce the overall distribution cost.

Originality/value – Unlike the previous researchers who examined the PDS from the social security perspective and tried to address specific problems to improve functioning of the PDS, this study looked at the problem as a supply chain-related problem and optimized the inventory parameters in one of the subsets of the PDS supply chain.

Keywords Simulation, Genetic algorithm, Inventory policy, Public distribution system

Paper type Research paper

1. Introduction

In the recent past, the focus of the society worldwide has been on providing adequate food of a good quality to the population. The prevalence of food inadequacy poses immense problems in most of the underdeveloped and developing nations. These problems relate to production, availability, wastage, and increasing food prices and can be attributed to complex multi-echelon food supply chains. These chains consist of four tiers, namely, producers, processors/distributors, retailers and customers. They are characterized by a large variety of products that are produced at different time periods, variation in demand pattern in terms of geography, uncertainty in the supply, and a time lag between production and consumption. There is also a variation in the mode of transportation used, inventory positions, and supply lead time (Lowe and Perckel, 2004; Kumar and Nigmatullin, 2011; Vlajic *et al.*, 2013). This variability in a food supply chain impacts all its stakeholders.

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The primary producers of food (farmers) suffer due to price variations, buyers (population at large) suffer as a result of unavailability and high prices and governments face problems associated with modifications in their food policies. Governments thus intervene in the food market as a reaction to these uncertainties and for enhancing the well-being of people. The intervention takes place at different stages/levels of the food supply chain and depends on the food policy of the governments. This includes policy of direct intervention through buying, storing, and distributing the food and policy of indirect intervention through subsidies. The major intervention is in the form of buying and maintaining national food stocks; buying, storing and distributing food (including targeted distribution, mid-day school meal and cooked food distribution through people's restaurants); and providing cash subsidies including conditional cash transfers (Ambekar *et al.*, 2015; Demeke *et al.*, 2009).

One of the major food security policies is run in India and was enacted in 2013 by the government through the National Food Security Act (2013). This policy necessitates that food grains be distributed at a subsidized price to almost 75 percent of the rural and 50 percent of the urban population (http://dfpd.nic.in/nfsa-act.htm). This distribution of food grains is through a mechanism popularly known as a public distribution system (PDS). The PDS is in operation at all stages of the food value chain.

The PDS is essentially involved in procurement, storage, and distribution of wheat and rice through different government agencies. The PDS covers about 23.5 percent of the rural and about 18 percent of the urban rice market and 14.6 percent of the rural and 9 percent of the urban wheat market (NSSO Survey, 2013). The share of the PDS is further increased due to the implementation of the National Food Security Act (2013). Procurement and storage are a large responsibility of the central government and are achieved through the Food Corporation of India (FCI). The FCI procures and stores food grains for further distribution through state government agencies. State government agencies/offices allocate food grains received from the FCI to fair price shops (FPSs) for the final delivery to beneficiaries. The PDS involves total 11,648 storage depots managed by different agencies such as FCI, central warehousing corporation, state warehousing corporation, regional co-operative marketing society, regulated market committee, private operators, etc. with total storage capacity of 57,662,363 metric tons of food grains (https://www.pdsportal.nic.in/ReportsView.aspx?rid=8). It distributes food grains to 2,320 lakhs households/8,134.92 lakhs individuals (http://dfpd.nic.in/1sGbO2W68mUlunCgKmpnLF5WHm/bulleten-151117.pdf) through 5.47 lakhs FPSs managed by private operators, cooperatives, women's self-help groups, village panchayats, urban local bodies and other self-help groups in 33 States/UTs spread across India (annual report, department of food and public distribution, 2015–2016; http://dfpd.nic.in/1sGbO2W68mUlunCgKmpnLF5WHm/AR-2015-16-ENG.pdf). Thus, it makes this chain a complex structure because of its objectives and size, number of different schemes implemented, and the number of actors involved (Ambekar *et al.*, 2015). There is a large time gap between the procurement and distribution of food grains. Out of 280.23 lakh MT of procured wheat (2014–2015) and 318.40 lakh MT of procured rice (2013–2014), only 292 lakh MT of wheat and 291 lakh MT of rice were distributed by state agencies. Moreover, about 250.91 lakh MT (46.7 percent) of food grain was diverted out of the system in 2011–2012 (Gulati and Saini, 2015). Further, there was 4,320 tonnes of damaged/non-issuable food grains with the government in 2015–2016. Further, the government spend Rs107,075.85 crore on the food subsidy in 2015–2016 (annual report, department of food and public distribution, 2015–2016; http://dfpd.nic.in/1sGbO2W68mUlunCgKmpnLF5WHm/AR-2015-16-ENG.pdf) but only 16 percent reached to the targeted population (Kattumuri, 2011). This raises questions about the efficiency of this supply chain. Researchers have attributed this mismatch to many issues. These issues are related to administration of the PDS and also those related to the present supply chain of the PDS (Ambekar *et al.*, 2015). Many steps have been undertaken by the Government of India for strengthening the PDS administration. Further, they have also suggested changes in the stocking and movement policies used for food grains in the PDS (Report of High Level Committee, 2015). Thus, there is a need to focus on the operational practice followed in the PDS supply chain. It is essential to optimize the operations at all stages of the PDS supply chain. The overall supply chain can be made more efficient through improvements in the micro-level practices of PDS supply chain so as to get practical solutions or through an integrated model that will capture the interaction between all actors involved in procurement, storage and distribution operations. A major improvement in the system can be achieved by implementing an optimized inventory policy at the distribution stage. This will not only minimize the distribution cost but will also help in deciding stock levels at different storage depots in the PDS.

In this study, we developed a simplified and usable model for the distribution stage of the PDS supply chain to minimize the total distribution cost. We used simulation optimization via the Genetic Algorithm (GA) on a C programming platform for modeling the distribution. We preferred GA because of its ability to handle complex real-life problems and can efficiently handle large inventory optimization problems involving many agencies at different levels of supply chain (Paul and Rajendran, 2011). Further, Daniel and Rajendran (2005) successfully used GA for optimizing the base stock levels in a single-product serial supply chain. However, their model does not consider review periods and is more generic. We used a similar approach for GA for this specific problem and also considered the review period as an optimization parameter.

The expected output of this model is optimized inventory policies (base stock level and review period) in the PDS distribution. An iterative process is used for getting optimized inventory polices at all stages of PDS distribution. A two-stage modeling approach was adopted for this purpose. In the first stage, a simulation model was developed for periodic review-based stock policy with appropriate assumptions. The objective here was to minimize the Total Supply Chain Cost (TSCC). The TSCC consists of three cost elements: ordering cost; holding cost; and shortage cost. The three cost elements, in turn, depend on inventory policy parameters such as review periods and base stock levels at various echelons. In the second stage, a GA-based optimization approach was used. The GA implementation is based on simulation for a given set of policy parameters. The aim of the GA is to identify an optimal set of policy parameters of the system. In particular, our model will be helpful in:

(1) analyzing the impact of various inventory-related costs on inventory policies (base stock levels and review periods) at all stages of food grain distribution;

(2) deciding about the stock levels to be maintained in storage depots;

(3) deciding about the transportation requirements between procurement center and storage depots and inter-depot food grain movement requirements; and

(4) comparing variations in stocking polices and inventory costs of the PDS distribution.

Unlike the previous researchers who examined the PDS from the social security perspective and tried to address specific problems to improve the functioning of the PDS, we looked at the problem as a supply chain-related problem and optimized the inventory parameters in one of the subsets of the PDS supply chain. As a result, present study will be useful to policy makers in improving PDS performance. This optimization of inventory policies helps actors in the PDS supply chain to choose appropriate policy parameters in the present inventory policy so as to reduce the overall distribution cost. Further, this study can be used by researchers working in the area of food security as a starting point to look at the problem from the supply chain angle. This study also contributes in a small way to the supply chain domain by providing a practical application of a commonly used optimization tool.

The rest of this paper is structured as follows: Section 2 provides the related literature. Section 3 presents our proposed model and the research setting, formulates the problem, and describes the implementation process. Section 4 reports our findings and provides a discussion on its implication for the PDS distribution. Finally, Section 5 concludes the study and presents future research directions.

2. Related literature

The PDS is implemented in India with the Noble objectives of providing food grains at an affordable price, providing minimum prices to farmers and maintaining buffer stocks for an emergency (Ambekar *et al.*, 2015, annual report Department of Food and Public Distribution, 2015–2016; http://dfpd.nic.in/1sGbO2W68mUlunCgKmpnLF5WHm/AR-2015-16-ENG.pdf). Under the PDS, beneficiaries are classified into three categories based on their household income-Below The Poverty Line, Antodya Anna Yojana and Above the Poverty Line-and are issued different cards that enable them to buy food grains at subsidized rates. Their entitlement and the prices they pay are based on the type of card the family holds (Nagpal and Kumar, 2012; http://dfpd.nic.in/?q=node/101). Altogether, the PDS distributes food grains to around 2,320 lakh households across India (based on the information from the web page: http://dfpd.nic.in/statement-reg-implementation-tpds.htm).

At the same time, the PDS has many shortcomings in its functioning. These include leakages (Gulati and Saini, 2015; Kattumuri, 2011; Mane, 2006; Nagavarapuy and Sekhriz, 2011, 2012; Ramaswami, 2002; Swaminathan, 2000), excess costs (Jha and Ramaswami, 2011), inactive participations (Khera, 2011; Nagavarapuy and Sekhriz, 2011, 2012), problems regarding operations of these supply chains (e.g. large-scale movement of food grains; Murthy and Ramanayya, 2007), poor offtake by states (Ramaswami, 2002) or problems that arise due to PDS implementation (e.g. speculation in the market and concentration on certain crops) (Ramaswami, 2002). Some of these problems are attributed to the identification of the beneficiaries of the system, their socioeconomic background, and other policy shortcomings (Ambekar *et al.*, 2015). These problems can be addressed by properly monitoring and controlling and by educating beneficiaries. There are other problems in the systems, which result from inappropriate storage and movement, mismatch between the supply (allocation of food grains by agencies to different FPSs) and demand (actual purchase of food grains by beneficiaries). The demand of the food grains is dynamic in nature and varies from month to month. This variability in the demand is due to non-purchase or purchase less than the eligibility by the households due to credit problems, the distance between the shop and home, non-availability of food grain during visits to the FPS, incorrect or low variety of food grain stocks, lack of awareness among cardholders about their entitled quantities, malpractices at the FPS, incorrect inclusion in the beneficiaries list, and the difference in social status between the shopkeeper and cardholders (Khera, 2011; Nagavarapuy and Sekhriz, 2011, 2012). The supply is based on based on estimates of the number of card holders rather than on actual purchases (Ramaswami, 2002). These problems can be solved by formulating an appropriate inventory policy for food grains in the distribution channel.

The final distribution of food grains to beneficiaries is the responsibility of the state government. They identify beneficiaries and decide on the monthly allocation of food grains to different FPSs. Food grains are issued to the FPS through a network of issue centers. These issue centers are fed by the various storage depots where the procured food grains are stored in the long term (Ambekar *et al.*, 2015).

There are various models (decision support system) available to aid decision makers like inventory management system, planning and scheduling systems, enterprise resource planning system, etc., for taking decision on different aspects of supply chain

(Keramati and Eldabi, 2011). However, none of these systems provides a readymade solution for modeling this distribution system as these tools fail to capture the distributed nature and heterogeneity of the actors present in the PDS and may not have capabilities to model day-to-day interaction between the actors. Traditional modeling tools such as linear programming, stochastic programming, risk programming, dynamic programming, stochastic dynamic programming and mixed integer programming fail to capture the complexity, dynamic and multi-faceted nature, and data requirements for real-life representation of this multi-echelon food supply chain (Krejci and Beamon, 2012) and therefore have limited applicability to model the distribution system of the PDS. Thus, this distribution chain can be designed and/or redesigned based on qualitative analyses (benchmarking) or through a need-based simulation model (Swaminathan *et al.*, 1998). Benchmarking also has limited applications because it does not provide future prospective and can only be suitable for understanding the current trends (Swaminathan *et al.*, 1998). A simulation approach would be more suitable in this context because simulation has experimentation capacity. Simulation can capture the dynamic nature of this supply chain, and it also reduces the risks related to actual implementation and failure (Kumar and Nigmatullin, 2011; Labarthe *et al.*, 2007; Li *et al.*, 2010; Lowe and Perckel, 2004).

Simulations are originally based on the principle of system dynamics (SD). SD is a computer simulation modeling technique used to formulate, understand, analyze, and discuss complex problems. A feedback loop is formed to understand the behavior of the system (Li *et al.*, 2010). SD can be used for what-if analyses and also for understanding the long-term operational needs of supply chains using total supply chain performance (Kumar and Nigmatullin, 2011). It can also be used for understanding the impacts of capacity constraints and impact of investments in capacity improvements on supply chain performance (Li *et al.*, 2010). Thus, it is suitable to model and check the actual performance of a supply chain and can also be used to understand the impact of changes in the system on the whole system.

Simulation is done to understand and predict the behavior of a system. It is done either for normative or descriptive purposes. Descriptive models are used for understanding supply chain performance, and normative models are used for improving system performance. The simulation approach uses two types of modeling: equation-based modeling; and agent-based modeling. Equation-based modeling presents the relationship between variables through equations and is executed in an iterative process. In every iteration, equations get evolved and observed in terms of changes in variables. In agent-based modeling, the behavior of each member (agent) of the system is observed. During the execution of the model, agents are allowed to interact with one another and the environment. The behavior of each agent is monitored, and the changes in the variables due to a particular behavior of the agent are noted (Barbati *et al.*, 2012; Labarthe *et al.*, 2007). Simulation modeling is performed with continuous simulation and discrete event simulation. Discrete event simulation is preferred to continuous simulation while modeling supply chains because the former is more realistic in modeling supply chains (Labarthe *et al.*, 2007; Swaminathan *et al.*, 1998; Van der Vorst *et al.*, 2000).

We prefer GA to other optimization tools because it is independent of the domain of applications and can be used for overcoming many general optimization problems, it leaves local optima and finds global optima, which makes it suitable for simulation where random outputs are generated and it needs only a minimum number of input parameters (Daniel and Rajendran, 2005). Moreover, GA has been used successfully to overcome many complex optimization problems (e.g. traveling sales men problem Choi *et al.*, 2003; scheduling problems Gonçalves *et al.*, 2002; Tokgöz *et al.*, 2015; multi-issue negotiation problems Ambad and Kulkarni, 2015; numerical optimization Bessaou and Siarry, 2001; Östermark, 2004; identifying best ranking method Razi and Shariat, 2017; forecasting corporate failure

Brabazon and Keenan, 2004; resource allocations Delias and Matsatsinis, 2009; inventory classification Guvenir and Erel, 1998 and inventory policy optimizations Daniel and Rajendran, 2005). The robustness with respect to starting points and inherent parallelism in the GA makes it suitable for problems with multimodal objective functions or irregular search space (partially) as in the present problem.

3. Description of the model for PDS distribution

Our model for the PDS distribution stage is based on the actual mapping of the PDS distribution stage as given in the literature of PDS supply chains. This is a multistage supply chain and consists of storage depots, issue centers, FPSs and card holders (Ambekar *et al.*, 2015). Figure 1 represents the supply chain network used in this study. The material movement flows from storage depots to card holders. The supply chain is governed by periodic review-base stock policy. All the members of this supply chain have their own holding, ordering and shortage cost. The FPS faces a demand that follows Poisson distribution. The demand is dynamic in nature and changes for each time period. In the remainder of this section, we briefly describe actors involved in this supply chain. For a detailed description of these actors and their interaction, the readers can refer to Ambekar *et al.* (2015).

3.1 Card holders

Card holders are the actual beneficiaries of the PDS. They purchase food grains from the FPS as per their eligibility and are the final customers in this chain. The quantity purchased and the time of the purchase of the food grain are based on the demand pattern and the availability of the stocks at the FPS. We assume that card holders purchase only one variety of food grain at a single purchase. The assumption is based on the problem of credit (Ambekar *et al.*, 2015; Khera, 2011; Nagavarapuy and Sekhriz, 2011, 2012) as described in the PDS literature. We also assume that if stocks are not available, the demand is backlogged for the given month. The assumption is based on the monthly eligibility of card holders.

3.2 FPS

FPSs are retailers in the PDS supply chain. The maximum number of FPSs depends on the number of licences issued by the state government. These retailers sell food grains to

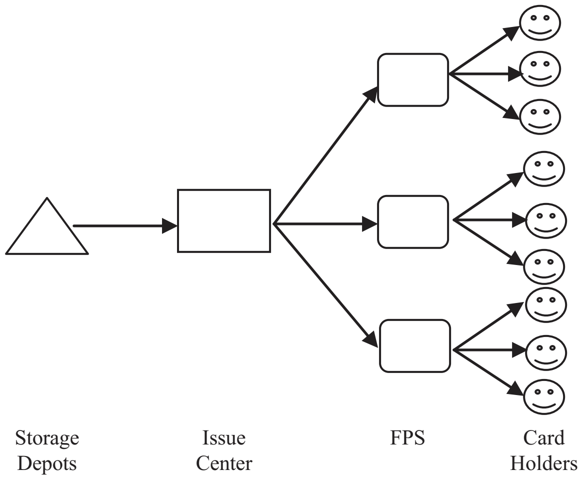

Figure 1.
Supply chain for food grain distribution in the PDS

card holders. The maximum sales made are equal to the eligibility of a particular card holder. We assume that the demand distribution for the FPS follows a Poisson distribution with parameter λ.

We assume that FPSs follow an order-up-to level inventory policy. They set review periods and a base stock level at each review period (presently, they follow monthly reviews and base stock levels are based on estimates of the number of card holders). The FPSs order quantities of food grains according to base stock levels and the actual stock position. The following sequence of events is applicable to an FPS:

- an FPS receives food grains from the issue center and updates the stock;
- it issues food grains to card holders if sufficient stock is available; otherwise, it backorders the excess demand; and
- it raises an order for food grain to the issue center, based on the available stock and demand.

3.3 Issue center

Issue centers are centers for the distribution of food grains. These are designated warehouses (storage depots) assigned by the state government/FCI. These centers distribute food grains to the FPS in a particular region/district. The maximum number of issue centers depends on the number of FPSs in a state. We assume that issue centers also follow an order-up-to level inventory policy. The demand for the issue center is equal to the orders raised by FPSs. The following sequence of events exists at issue centers:

- the issue center receives food grains from the storage depot and updates the stock;
- it issues food grains to the FPS if sufficient stock is available; otherwise, it backorders the excess demand; and
- it raises an order for food grains based on available stock and demand, to the storage depot.

3.4 Storage depots

A storage depot is a warehouse of food grains. These are managed and owned by the FCI, central warehousing cooperation, state warehousing cooperation or by private firms. The demand for storage depots is equal to the orders raised by issue centers. The storage depot supplies food grains to issue centers and is assumed to have an unlimited capacity. The assumption of unlimited capacity is based on the fact that the movement of food grains took place between storage depots. The following sequence of events exists at storage depots:

- storage depots receive food grains from purchase centers (i.e. the place where farmers sell their crops to the PDS system) or other storage depots and update the stock; and
- storage depots move the stock to the issue center if sufficient stock is available; otherwise, they backorder the excess demand.

3.5 Mathematical formulation

For improving the performance of the distribution system, we propose to optimize inventories in the system. This optimization is helpful not only in reducing the overall distribution cost but also in improving some of the other performance measures such as average stocks at the FPS. The objective is to minimize system-wide cost, namely, the ordering cost, the holding cost and the shortage/backorder cost for all the members of the supply chain. The PDS supply chain is simulated for analyzing performance of the distribution system (TSCC) with respect to every base stock level and review period. These two parameters are generated through GA. This supply chain is simulated for the given cardholders demand for a specific period and TSCC is collected for the period. Thus, the objective function for the PDS distribution stage supply chain is:

Minimize: System ordering cost + System holding cost + System backorder cost,

$$\text{Min TSCC} = \sum_{i=1}^{n\_ic}\sum_{j=1}^{n\_fps_i}\frac{c_{ij}^{\text{order}}}{T_{ij}} + \sum_{i=1}^{n\_ic}\frac{c_i^{\text{order}}}{T_i} + \sum_{i=1}^{n\_ic}\sum_{j=1}^{n\_fps_i} h_{ij}\overline{I_{ij}} + \sum_{i=1}^{n\_ic} h_i\overline{I_i} + h_k\overline{I_k} + \sum_{i=1}^{n\_ic}\sum_{j=1}^{n\_fps_i} b_{ij}\overline{B_{ij}},$$

where *TSCC* is the total supply chain cost; c_{ij}^{order} the cost of ordering at the *j*th FPS of the *i*th issue center; c_i^{order} the ordering cost at the *i*th issue center; h_{ij} the holding cost rate at the *j*th FPS of the *i*th issue center; h_i the holding cost rate at the *i*th issue center; h_k the holding cost rate at the *k*th storage depot; b_{ij} the shortage cost rate at the *j*th FPS of the *i*th issue center; T_{ij} the review period at the *j*th FPS of the *i*th issue center; T_i the review period at the *i*th issue center; $\overline{I_{ij}}$ the average on-hand inventory at the *j*th FPS of the *i*th issue center; $\overline{I_i}$ the average on-hand inventory at the *i*th issue center; I_k the average on-hand inventory at the *k*th storage depot; $\overline{B_{ij}}$ the average backorder at the *j*th FPS of the *i*th issue center.

Equations (A1) to (A8) in given in Appendix 1 represent the mathematical formulations of event chronologically at FPS; Equations (A9) to (A17) given in Appendix 2 detail the mathematical formulations of the events at issue center and Equations (A18) to (A23) given in Appendix 3 detail mathematical formulations of the events at storage depot. Equations (A1), (A9) and (A18) inform the on-hand inventory position at the beginning of every period for the respective member of this distribution chain. Similarly, Equations (A7), (A8), (A16) and (A17) represent the updates in the on-order inventory of the FPS and issue centers. The FPS and the issues centers either issue the food grains to the next member(s) from on-hand inventory (updated in Equations (A3), (A4) and (A13)) or backlog the demand at end of the period and are updated in Equations (A5) and (A6).

3.6 Simulation study

In this study, we propose to simulate the distribution system and use a GA for inventory optimization. The study optimizes the TSCC and uses GA to determine the base stock levels and review periods. The proposed simulation optimization via the GA method is represented in Figure 2.

For optimizing the inventory, we considered one storage depot, two issue centers, and eight FPSs. The storage depot supplies food grains to the issue centers and is assumed to have an unlimited capacity. Each of these issue centers caters to four FPSs. Demand is generated for each FPS based on cardholders' purchase, and the base stock levels and review period at each delivery node are optimized to minimize the total inventory cost. The problem is represented in Figure 3. We consider a small problem for the simplification of the solution methodology and can easily increase the number actors to the actual numbers in the PDS distribution network for district or a state.

The present problem thus has 20 parameters for optimization. It includes ten review periods (4 + 4 + 1 + 1) and ten base stock levels (4 + 4 + 1 + 1).

For the simplification of the solution in our model, we assume that holding cost, ordering cost and backorder costs are the same at all the nodes of the supply chain. This cost can be easily updated to the actual cost, and the model is run accordingly. We considered different

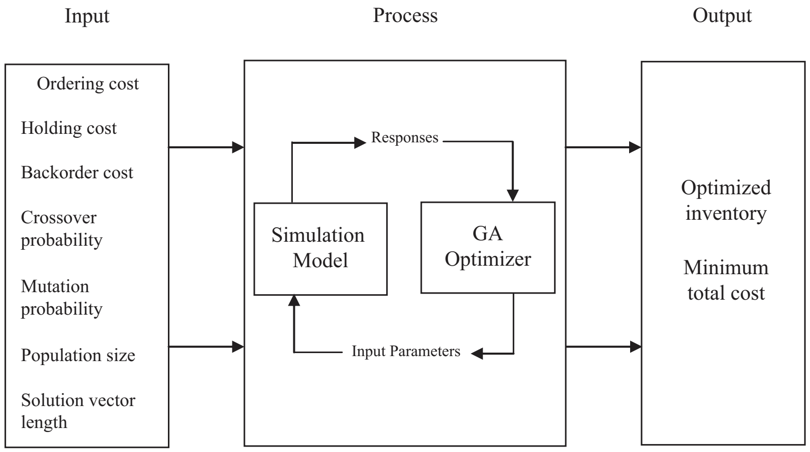

Figure 2. Proposed simulation optimization via the GA method

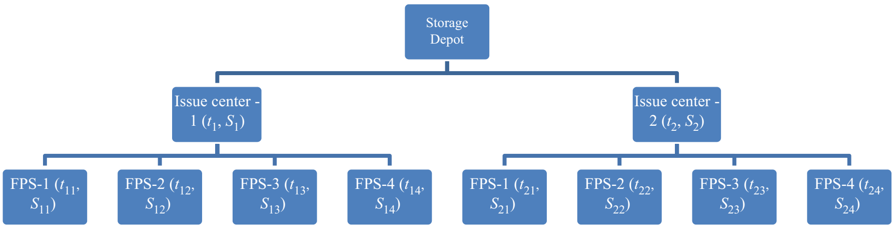

Figure 3. Optimization problem for simulation via the GA

combinations of holding cost and backorder cost for understanding the impact of these costs on the inventory policies at all stages of this supply chain. The combinations of costs are given in Table I.

3.7 Experimental design

Simulation experiments are carried out with a population size of 100 and 200 generations. The mean of expected backorder levels and on-hand inventory at the FPS/issue center/storage depot for all these replications is taken into consideration for the evaluation of parameter values.

We used three different combinations of backordered cost and holding cost. This resulted in three different experiments for comparing the effect of these parameters on the total cost of the system. The holding cost is the base for all these experiments, and the backorder cost is set at:

- the same level as that of the holding cost;
- twice the holding cost; and
- 1.5 times the holding cost.

Cost	Scenario 1	Scenario 2	Scenario 3
Ordering cost	15	15	15
Backorder cost	2	4	3
Holding cost	2	2	2

Table I. Combination of costs used for the GA

The ordering cost in all these experiments is kept constant.

We assume the following parameters for the experiment:

- The demand is generated at FPS. It follows a Poisson distribution with the following mean parameters (based on the actual purchases at eight FPSs in the Indore District of Madhya Pradesh, India, for a period of 50 months):

FPS−11	FPS−12	FPS−13	FPS−14	FPS−21	FPS−22	FPS−23	FPS−24
17.22328	7.55313	2.65895	4.18178	9.06611	1.86423	16.71798	2.72171 ’

- There are no back orders at the beginning of the simulation.
- The supply chain follows a fixed interval of ordering between all stages.
- The resupply is based on the current demand and previous unfulfilled demand.
- Both the FPS and the issue center have the same costs for ordering, holding and backorders.
- The search space for base stock level is lower bound = 0, upper bound = 100.
- The search space for the review period is lower bound = 0, upper bound = 30.

3.8 Input parameter

- Population size = 100.
- Total no. of generations = 200.
- Crossover probability = 0.8.
- Mutation probability = 0.1.
- Mutation parameter = 0.2.
- Number of variables = 20.

Lower and upper bounds of review periods at the FPS:

- $1 \leqslant x[1] \leqslant 30$.
- $1 \leqslant x[2] \leqslant 30$.
- $1 \leqslant x[3] \leqslant 30$.
- $1 \leqslant x[4] \leqslant 30$.
- $1 \leqslant x[5] \leqslant 30$.
- $1 \leqslant x[6] \leqslant 30$.
- $1 \leqslant x[7] \leqslant 30$.
- $1 \leqslant x[8] \leqslant 30$.

Lower and upper bounds of review periods at the divisions:

- $1 \leqslant x[9] \leqslant 30$.
- $1 \leqslant x[10] \leqslant 30$.

Lower and upper bounds of base stock levels at the FPS:

- $0 \leqslant x[11] \leqslant 100$.
- $0 \leqslant x[12] \leqslant 100$.

- $0 \leqslant x[13] \leqslant 100$.
- $0 \leqslant x[14] \leqslant 100$.
- $0 \leqslant x[15] \leqslant 100$.
- $0 \leqslant x[16] \leqslant 100$.
- $0 \leqslant x[17] \leqslant 100$.
- $0 \leqslant x[18] \leqslant 100$.

Lower and upper bounds of base stock levels at the FPS:

- $0 \leqslant x[19] \leqslant 100$.
- $0 \leqslant x[20] \leqslant 100$.

Details of experiments. As discussed in the previous section, we used three different combinations of the holding and backorder costs for generating the three scenarios. Table II gives the details of the scenarios used for the experiment. The experiments were carried out with a run length of 200 days, and the TSCC was noted.

The experiments were replicated 30 times.

This study considers two sets of parameters: review period (*t*); and base stock levels (*s*). This is represented as genes in the model. The solution representation is shown in Figure 4.

In the typical GA terminology, each *T* and *S* is known as an allele. The working of GA is described in the following steps, as adopted from Daniel and Rajendran (2005).

3.9 Steps in the proposed GA

- Step 0: input max*_gen* = 100; *pop_size* = 100; CR = 0.8; MR = 0.2.
- Step 1: initialize the system with *no_gen* = 0.
- Step 2: generate the initial population: The initial population is generated with *n* feasible solutions (equal to *pop_size*). Each parameter *i* is set randomly using the Hyper latin cube procedure in the range $[par_i^{LL}, par_i^{UL}]$. This initial population is taken as *par_pop*.
- Step 3: evaluate each feasible solution: Each feasible solution in *par_pop* is evaluated by simulating the system, and the objective function value is obtained for the given parameter setting represented by the solution.
- Step 4: store the best solution.

Parameters	Scenario 1	Scenario 2	Scenario 3
Description	BC = HC	BC = 2 × HC	BC = 1.5 × HC
Ordering cost	15	15	15
Holding cost	2	2	2
Backorder cost	2	4	3

Table II. Details of the scenarios used for the experiment

$T_{1,1}$	$T_{1,2}$	.	.	$T_{2,4}$	T_1	T_2	$S_{1,1}$	$S_{1,2}$	.	.	$S_{2,4}$	S_1	S_2	S_{SD}

Figure 4. The solution representation for the GA optimization

- Step 5: fill up the mating pool using the tournament selection procedure.
- Step 6: perform the crossover operation: Subject solutions in the mating pool to crossover by selecting two successive solutions at a time with a probability of CR, by using a double-point crossover operator. Place the child solutions inint *er_pop*.
- Step 7: perform the mutation operation: Subject the n solutions int *er_pop*to parameter-wise mutation with a probability of MR.
- Step 8: copy int *er_pop* to *par_pop*.
- Step 9: increment $no\_gen = no\_gen + 1, \ldots$ If ($no\_gen \leqslant \max\_gen$) then return to Step 3, Else go to Step 10.
- Step 10: Stop: the best solution among the solutions in the final *par_pop* and its TSC constitutes the solution to the problem. Let the best solution be represented by $x^* = (T^*_1, T^*_2, \ldots, T^*_{10}; S^*_1, S^*_2, \ldots, S^*_{10})$.

4. Results and discussion

The performance of the distribution system (total distribution cost) was studied for a given set of backorder cost and holding cost. The base stock levels and review periods were optimized by using the proposed method. The simulation results are presented in Table III. Table III provides details of the results with a given scenario at each of the distribution node. It also summarizes the details of the TSCC with these scenarios.

Parameters	Scenario 1	Scenario 2	Scenario 3
Best ever fitness (TC)	154.568800	233.165000	168.269200
Maximum value	230.692200	494.067400	294.644400
Minimum value	156.529000	237.923800	168.760000
Average	164.339116	307.616788	184.690076
Mutations	39,956	39,817	39,943
Crossovers	8,003	7,990	8,016
Review period at			
FPS-11	3	2	2
FPS-12	3	2	2
FPS-13	3	2	2
FPS-14	4	6	2
FPS-21	1	2	1
FPS-22	1	2	1
FPS-23	1	1	1
FPS-24	1	4	1
Issue center 1	1	1	1
Issue center 2	1	2	1
Base stock levels at			
FPS-11	23	20	21
FPS-12	8	8	7
FPS-13	16	21	11
FPS-14	9	26	10
FPS-21	1	6	2
FPS-22	17	24	18
FPS-23	3	12	3
FPS-24	12	0	0
Issue center 1	52	48	47
Issue center 2	31	75	33

Table III.
Results of simulation via the GA

Table III shows that base stock levels at issue centers are higher as compared to those in the FPS. This is because the aggregations of the inventory help in gaining the economy of the scale at the back end of the supply chain. This aggregation of the stocks at the back end of the supply chain will help in not only reducing the overall cost by centralization but also in risk pooling across members. Further, in a serial supply chain like that of the distribution in the PDS, any shortage at any level of the supply chain has its impact on downstream members because upstream members act as feeders to downstream members. It is therefore necessary that upstream members should hold higher stocks to avoid having an impact on downstream members. We observed that the base stock levels at issue centers are higher as compared to those in the FPS, which fits the above logic. Therefore, in the PDS distribution while deciding on the base stock periodic review inventory policy (present policy), policy makers should consider the aggregation of inventories at the issue centers. This aggregation will help in increasing the availability, reducing the risk and can also capture the advantages of centralization. Moreover, issue centers are under the direct control of the government, so any changes in the distribution policy (e.g. temporary increase in the eligibility, addition or deletion of an FPS, change in the buffer stock norms) can easily be implemented. Further, the management of food stocks particularly in terms of their shelf life can be further improved by using technology, planning and controlling food stocks as per their shelf life, effectively controlling storage requirement, physically and or chemically treating food grains. Additionally, the higher stocks at the issue centre allow the policy makers the flexibility to modify the present policies in terms of review periods, modifications in the number and distribution of the card holders to FPSs and adjusting the requirements during disaster management. This aggregation can further be useful for an effective transportation of food grains. The inbound transportation cost at issue centers can get reduced because of larger lot sizes and the outbound transportation cost can be further optimized by solving this as a transhipment problem. Thus, for an effective control of the stocks in the present distribution system, the policy makers can add capacities to the present issues centres or can create additional issues centres that hold aggregate stocks of all the FPSs in a particular area. This new facilities can make use of all modern storage methods/technologies so as to improve the overall performance the PDS supply chain.

It is observed that the total TSCC is less in scenario 1, that is, when backorder cost is equal to the holding cost. This equal weight scenario decreases both the tendency to overstock for avoiding backorders and the tendency to understock to reduce the holding cost. Adding the penalty for backorders will also help in improving the availability of food grains.

As shown in the results, the policy makers can introduce a penalty cost equivalent to the holding cost in the PDS. The introduction the penalty cost to all the members of the PDS distribution chain will have a long-term impact on the system cost, supply chain performance and the food security scenario. With the introduction of the penalty cost to the state agencies (issue centres), the chances of delays in deliveries of food grains to the FPSs will be reduced and the tendencies of the state governments to lift fewer stocks as compared to their allocations will be minimized. This will improve the availability of the food grains at the FPS level. Further, the penalty cost to the FPS will reduce the tendency of FPS owners to understock or to divert food grains to the open market. This will help in the easy availability of food grains and will also improve the offtake figures by card holders.

Another interesting observation in terms of review periods is that review periods for the customers (FPSs/issue centers) served by the same supplier are almost similar. This is because of the similarity in processing and other activities of members. This suggests the requirement of change in the present system of monthly review across India to a differential review period based on the members of the supply chain involved in the particular region. Moreover, the optimized review period in relation to the base-stock levels allows a continuous and smooth movement of food grains in the system. This system as compared to the present monthly review across the distribution network ensures the availability of food grains during visits of card holders in the FPS. This has been considered as one of the major problems in the PDS literature. This along with the effective use of technology, such as RFID and mobile communication, helps governments in reducing illegal diversions of food grains.

Figures 5–13 capture the convergence of the proposed GA toward the average, best, and worst solutions. The figures are based on traces of the minimum value of the TSC (best value of the objective function) obtained up to a given generation, till the termination condition is met.

5. Conclusions

This paper presents a method to optimize the inventory policies of the PDS distribution stage. It uses simulation via GA for optimizing the base stock levels and review periods in this serial supply chain with the objective of reducing TSCC. It presents the impact of different combinations of the holding and backorder cost on the overall distribution cost. Although food security has globally grown in importance in recent years, analytical research in this area is still limited. Our study contributes in this domain through a readily useable quantitative model for improving the inventory performance of the food grain supply chain. The present study will be useful to policy-makers in improving the performance of the PDS. It will act as a guide for various decision-makers involved in the operations of the PDS in designing and improving their operations. The modeling of the PDS will help agencies involved in the PDS

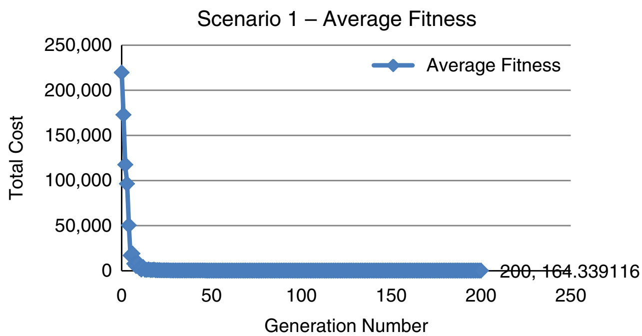

Figure 5.
Convergence of GA (scenario 1) for average fitness

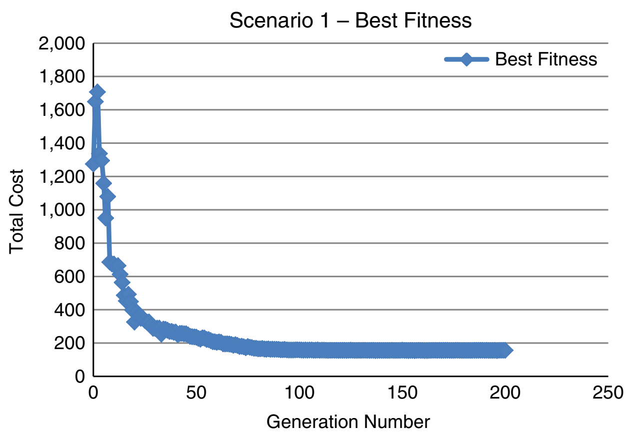

Figure 6.
Convergence of GA (scenario 1) for best fitness

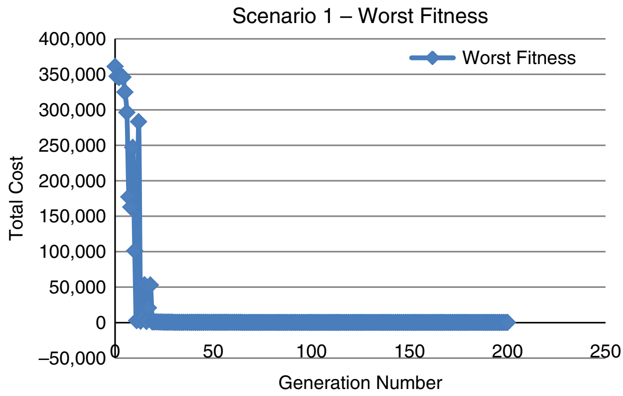

Figure 7. Convergence of GA (scenario 1) for worst fitness

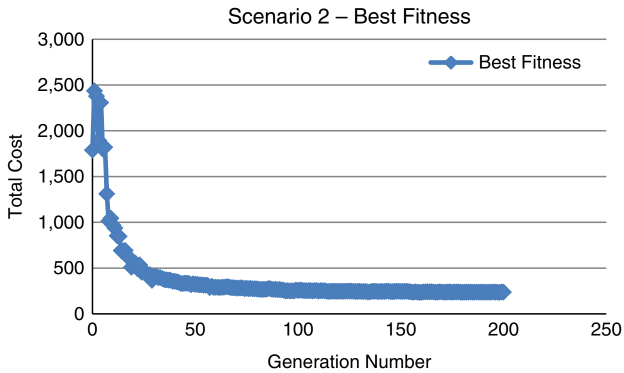

Figure 8. Convergence of GA (scenario 2) for best fitness

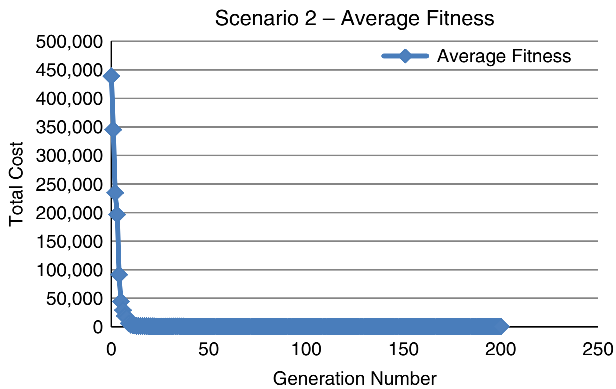

Figure 9. Convergence of GA (scenario 2) for Average fitness

supply chain to improve their performance, so that the actors in the supply chain can develop their strategies for improving the food security situation.

This work can be extended further by including other stages of the PDS in our model. Further, our model can be improved by considering other interactions between the members

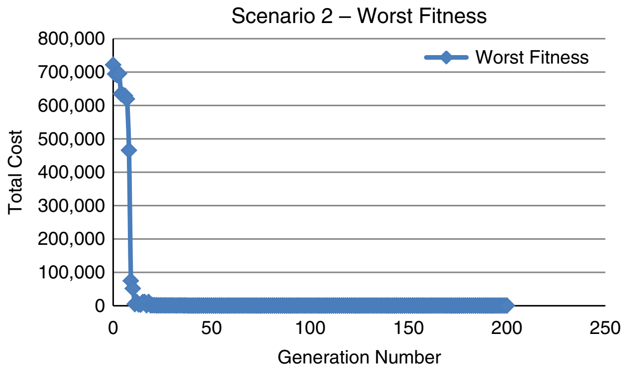

Figure 10.
Convergence of GA (scenario 2) for worst fitness

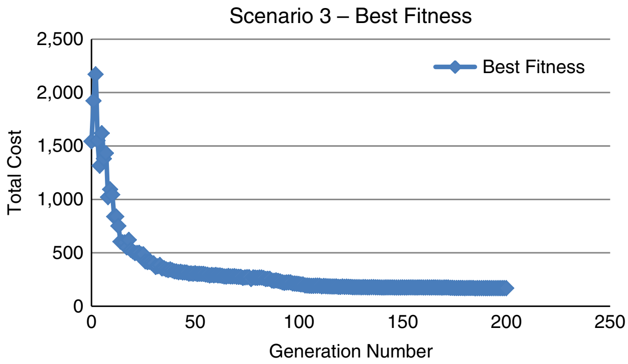

Figure 11.
Convergence of GA (scenario 3) for best fitness

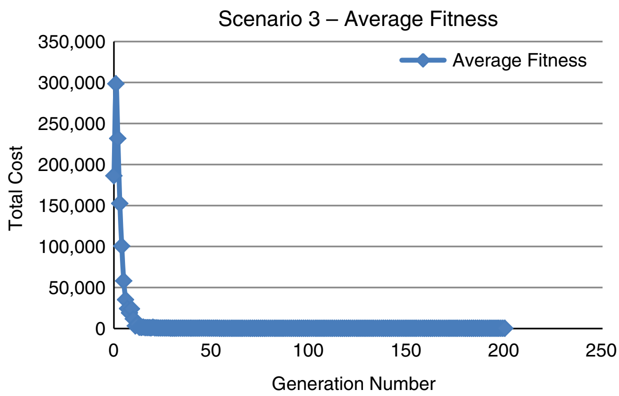

Figure 12.
Convergence of GA (scenario 3) for average fitness

of this supply chain by using a multi-agent system. A sensitivity analysis of the other the important inventory parameters can also be helpful to show some policy implications. Further, future study can work on the optimization of the food grains inventories in the PDS using a continuous review inventory system and can also consider the optimization of the inventory policies with a transhipment option.

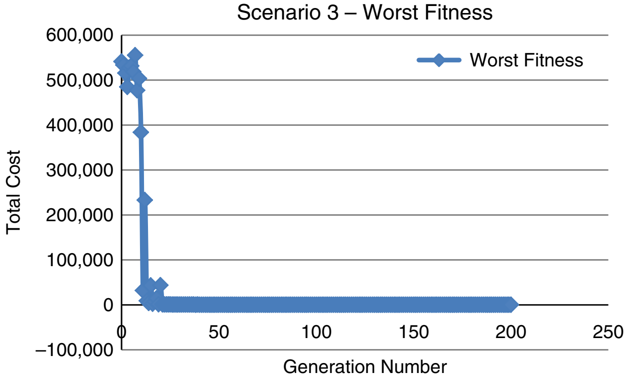

Figure 13. Convergence of GA (scenario 3) for worst fitness

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Appendix 1. Mathematical representations of the events at Fair Price Shop (FPS)

Notations used

β_{ij} = Base stock level of food grains at FPS j of ith issue center at time ($j = 1, 2, \ldots, n\_fps_i$), where n_fps_i = number of fair price shops in ith issue center:

- $O_{ij}(t)$ = Opening stock of food grains at FPS j of ith issue center at time t.
- $CS_{ij}(t)$ = Closing stock of food grains at FPS j of ith issue center at time t.
- $QR_{ij}(t)$ = Quantity of food grains received by FPS j from issue center i at time t.
- $D_{aj}(t)$ = Quantity of food grains issued to AAY card holder a by FPS j at time t.
- $D_{bj}(t)$ = Quantity of food grains issued to BPL card holder b by FPS j at time t.
- $D_{cj}(t)$ = Quantity of food grains issued to APL card holder c by FPS j at time t.
- $QI_{ij}(t)$ = Quantity of food grains issued at FPS j of issue center ith at time t.
- $QB_{ij}(t)$ = Quantity of food grains back ordered by FPS j of ith issue center at time t.
- $QO_{ij}(t)$ = Quantity of food grains ordered by FPS j of ith issue center at time t.
- I_{ij} = Average on-hand inventory at the jth FPS of ith issue center.
- B_{ij} = Average backorder at the jth FPS of ith issue center.

Opening stock:

$$O_{ij}(t) = CS_{ij}(t-1). \tag{A1}$$

Quantity received:

$$QR_{ij}(t) = QI_{ij}(t-1). \tag{A2}$$

Quantity issued:

$$QI_{ij}(t) = \sum_{a=1}^{n} D_{aj}(t) + \sum_{b=1}^{n} D_{bj}(t) + \sum_{c=1}^{n} D_{cj}(t), \tag{A3}$$

$$if \left(\sum_{a=1}^{n} D_{aj}(t) + \sum_{b=1}^{n} D_{bj}(t) + \sum_{c=1}^{n} D_{cj}(t) \right) \leqslant O_{ij}(t).$$

Otherwise:

$$QI_{ij}(t) = O_{ij}(t). \tag{A4}$$

Quantities backordered:

$$QB_{ij}(t) = \left(\sum_{a=1}^{n} D_{aj}(t) + \sum_{b=1}^{n} D_{bj}(t) + \sum_{c=1}^{n} D_{cj}(t)\right) - QI_{ij}(t). \tag{A5}$$

Closing stock:

$$CS_{ij}(t) = O_{ij}(t) + QR_{ij}(t) - QI_{ij}(t). \tag{A6}$$

Quantity ordered:

$$QO_{ij}(t) = \beta_{ij} - CS_{ij}(t). \tag{A7}$$

$$if\ CS_{ij}(t) \leqslant \beta_{ij}.$$

Otherwise:

$$QO_{ij}(t) = 0. \tag{A8}$$

Appendix 2. Mathematical representations of the events at issue center

Notations used

β_i = Base stock level of food grains at issue center i at time ($i = 1, 2, \ldots, n\_ic$), where, n_ic = number of issue centers:

- $O_i(t)$ = Opening stock of food grains at issue center i at time t.
- $CS_i(t)$ = Closing stock of food grains at issue center i at time t.
- $QR_{ki}(t)$ = Quantity of food grains received by issue center i from storage depot k at time t ($k = 1, 2, \ldots, o$), where o = number of storage depots.
- $QI_{ki}(t)$ = Quantity of food grains issued to ith issue center from kth storage depot at time t.
- $QI_i(t)$ = Total quantity of food grains issued at issue center i at time t.
- $QB_i(t)$ = Quantity of food grains back ordered by issue center i at time t.
- $QO_{ki}(t)$ = Quantity of food grains ordered by issue center i to kth storage depot at time t.
- I_i = Average on-hand inventory at the ith issue center.
- B_i = Average backorder at the ith issue center.

Opening stock:

$$O_i(t) = \mathrm{CS}_i(t-1). \tag{A9}$$

Quantity received:

$$QR_{ki}(t) = QI_{ki}(t-1). \tag{A10}$$

Quantity issued:

$$QI_{ki}(t) = QO_{ki}(t-1) \qquad if\ QO_{ki}(t-1) \leqslant O_i(t). \tag{A11}$$

Otherwise:

$$QI_{ki}(t) = O_i(t). \tag{A12}$$

$$QI_i(t) = \sum_{i=1}^{n\_ic} QI_{ki}(t). \tag{A13}$$

Quantities backordered:

$$QB_i(t) = QO_{ki}(t-1) - QI_i(t). \tag{A14}$$

Closing stock:

$$CS_i(t) = O_i(t) + QR_{ki}(t) - QI_i(t). \tag{A15}$$

Quantity ordered:

$$QO_{ki}\ (t) = \beta_i - CS_i(t) \qquad if\ CS_i(t) \leqslant \beta_i. \tag{A16}$$

Otherwise:

$$QO_{ki}(t) = 0. \tag{A17}$$

Appendix 3. Mathematical representations of the events at the storage depot

Notations used

- $O_k(t)$ = Opening stock of food grains at storage depot k at time t.
- $CS_k(t)$ = Closing stock of food grains at storage depot k at time t.
- $QI_{ki}(t)$ = Quantity of food grains issued at storage depot k to issue center i at time t.
- $QI_k(t)$ = Total quantity of food grains issued at storage depot k at time t.
- $QB_k(t)$ = Quantity of food grains back ordered by storage depot k at time t.
- I_k = Average on-hand inventory at the kth storage depot.
- B_k = Average backorder at the kth storage depot.

Opening stock:

$$O_k(t) = CS_k(t-1). \tag{A18}$$

Quantity issued:

$$QI_{ki}(t) = QO_{ki}(t-1) \qquad if\ QO_{ki}(t-1) \leqslant O_k(t). \tag{A19}$$

Otherwise:

$$QI_{kj}(t) = O_i(t). \tag{A20}$$

$$QI_k(t) = \sum_{i=1}^{n} QI_{ki}(t). \tag{A21}$$

Quantities backordered:

$$QB_k(t) = QO_{ki}(t-1) - QI_k(t). \tag{A22}$$

Closing stock:

$$CS_k(t) = O_k(t) - QI_i(t). \tag{A23}$$

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