Structural Mapping of Public Distribution System using Multi-Agent Systems

1. Introduction

Food security is an important agenda in government policies across all nations, because a prime objective of any society is to provide adequate and quality food to its citizens. When there are constraints on the production of food, an efficient distribution system becomes necessary in order to ensure that affordable food is available to the population. The distribution system should ensure minimum losses at all stages of product movement, minimise the cost incurred during the movement from farm to fork, and make food available throughout the year. In other words, an efficient supply chain management is required for food.

There is a high degree of uncertainty in the supply (production) of food grains. The supply of food grain is affected by the weather conditions, geo-physical characteristics of the region, the irrigation facilities available, the land holding pattern of the region, and local food habits, prices and supply in the previous year, the demand for particular types of food, intermediaries present in the market, process technologies and government policies related to the pricing system and trade legislation.

Variations in the supply chain have a direct impact on both consumers and producers. Supply conditions affect the population at large in terms of both sufficiency and affordability of the food, and farmers face large variations in the prices they receive. Moving agricultural produce efficiently from the farm to the consumer would help both parties.

To assure the availability of food to a large proportion of the population at affordable prices and also to assure cost plus returns to farmers, several governments intervene in the supply chain of food grains either directly by buying and distributing the food grains or indirectly by providing

subsidies. One of the largest government programmes in the world is executed in India. In this Public Distribution System (PDS), the government has a direct presence in all stages of the Food Grain Supply Chain (FGSC), namely, procurement, storage and distribution; see figure 1. The PDS covers 242.912 million households (Ministry of Consumer Affairs, Food and Public Distribution, Govt. of India). It has procured of 72.19 million tonne, stored 62.78 million tonnes and distributed 59.76 million tonnes of food grains in year 2012-13 (Reserve Bank of India, ON595).

Insert Figure 1 about here

But even after the direct presence of the government, high food inflation persists in India, which raises questions about the efficiency of the supply chain (Basu, 2011). The inefficiencies in the PDS are due to the very high degree of complexity coming from its size, geographical spread, which covers the entire country, number of entities involved and the strict hierarchical structure present in the system. Moreover, the research addressing PDS from a supply chain management perspective either describes the supply chain or analyses it from one of the niche areas of supply chain. There is a need for a study that will integrate all the operations across various organisations. This will act as a tool to capture interactions among actors so as to bring fairness and transparency in the system.

This study attempts to develop a structural mapping of the Indian PDS based on the practices followed by global food supply chains. In this, the entire PDS supply chain from purchase to the distribution is mapped in detail by integrating the various stages involved in the PDS supply

chain. It will use Multi-Agent system (MAS) to map the PDS as MAS has properties which can able to handle the complexities and also provide method to understand and model the interaction among the actors. In this context, it will try to address following questions:

a. How does the PDS work?

b. What are the problems and how can these problems in the PDS be addressed?

c. What are the focus areas of studies in global food supply chain research? What are the characteristics of a food supply chain?

d. How are food supply chains modeled in the literature?

e. What is Multi-Agent System (MAS)? How and why is MAS useful for mapping the PDS?

f. How can various stages of PDS functioning be mapped so that integrated decision-making can be done?

g. How can performance of this supply chain can be measured?

Similar to the trends in the research in the food supply chain, the present study integrates the various actors of the PDS supply chain so that over all distribution cost and risk in the supply of the food grain is reduced. This will be helpful in improving the food security in Indian context. More specifically, 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. It is also helpful to researchers in this area as it provides all the details related to the functioning of the PDS. It presents an innovative method to model the food supply chain using MAS.

The rest of the paper is organised as follows. We first describe related literature in section 2, 3 and 4. In Section 2 we discuss functioning, complexities and problem areas in the PDS. Section 3 describes the food security measures used across world. Section 4 describes food supply chain: its major areas of study; modelling of food supply chains; and MAS based supply chain modelling. Section 5 describes methodology followed in the study. Section 6 describes our modelling approach for the PDS in India and Section 7 list down the proposed performance measures for model. The final section concludes the study and suggests future directions for modelling the PDS.

2. The Public Distribution System (PDS) in India

The focus of the PDS is on the purchase and distribution of food grain, with a concentration on rice and wheat (Gulati et al., 2009). It is done either directly by government departments or through public sector enterprises. The objective of this system is social well-being rather than profit. This system has three major objectives:

- To provide food security to the deprived section of the population by distributing a certain quantity of food grain at a subsidised price through a network of Fair Price Shops (FPS).
- To maintain a buffer stock in order to stabilise prices (by releasing stocks when there is a shortage in the market) and to provide a cushion for emergencies such as drought.
- To provide fair prices to farmers by directly purchasing their produce at a Minimum Support Price (MSP) that is decided by the Commission of Agriculture Cost and Prices (CACP).

The scheme is implemented by the central government and the governments of the States and Union Territories, along with numerous intermediary organisations, such as the Food

Corporation of India (FCI), the Central Warehouse Corporation (CWC), State Food Corporations and State Marketing Federations. The central government's role is to procure, store, allocate and transport food grains to the states; these activities are carried out through the FCI. The state governments allocate the food grain to FPS within the state, identify beneficiaries, issue ration cards and monitor the distribution of grain through its district offices and other state agencies (http://dfpd.nic.in/fcamin/annualreport/AnnualReport201213.pdf).

In June 1997, the PDS system shifted from universal coverage to focus on the poor and is now referred to as the targeted public distribution system. Under the new system, beneficiaries are classified into three categories based on their household income—Below the Poverty Line (BPL), Antodya Anna Yojana (AAY) and Above the Poverty Line (APL) and are issued different cards that enable them to buy food grain at subsidised prices. 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).

The functioning of the PDS requires continuous interaction among various government agencies and private organisations. Most of these processes are interlinked and decisions at any stage impact the overall performance of the system. However, decision-making is distributed across various government departments/organisations, and each department solves sub-problems based on its objectives and constraints. However, these local improvements could be contradictory and directly affect the performance of the whole supply chain. (Ahluwalia, 1993; Gulati *et al.*, 2009; Jha and Ramaswami, 2010, 2011; Kattumuri, 2011; Khera, 2011; Kotwal, et *al.*, 2011; Nagavarapuy and Sekhriz, 2011, 2012).

2.1. Problems in the PDS

The public distribution system has been criticised for its functioning, particularly for pilferage, poor delivery of services, lack of transparency and the failure to change the hunger situation of BPL families (Ahluwalia, 1993; Gulati *et al.*, 2009; Kattumuri, 2011). Problems have been noted in the allocation policy, storage, distribution, purchasing practices, etc. The cost break-up of the PDS system shows that the problem lies in implementation and malpractices. The cost can be broken up as illegal diversion costs (43%), excess costs (28%), income transfer to the non-poor (19%) and income transfer to the poor at just 10% (Jha and Ramaswami, 2010; Kotwal *et al.*, 2011). The illegal diversion is the outcome of leakage, income transfer to the non-poor is due to inclusion errors, and excess cost is due to practices used in procurement, storage and movement of food grains. The main issues associated with the PDS are presented in table 1 below.

Insert Table 1 about here

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3. Food security Measures across World:

Similar programmes are implemented in other developing countries for providing food security through government intervention. These include programmes to increase food production, maintenance of national food stocks for food security, public food distribution, distribution of cash subsidies or food coupons. Table 2 below gives the list of selected countries which uses these policies either partially or in total in short or long term basis.

Insert Table 2 about here

Most of the Asian countries such as China, Bangladesh, Pakistan, Indonesia, Philippines were using food rationing programmes similar to the PDS in the past for providing food security and price stabilisation. During the course of time due to economic development and food self-sufficiency most of the countries shifted the policy focus from food rationing to other measures for providing the food security. The People republic of China introduced the 'unified grain procurement and sale system' in 1953. Under this system the state grain agencies were the only buyer and seller of food grains and coupons were provided to the urban population which they used for buying their food grain requirements from the distribution agencies including government grain stores, restaurants, and manufactured food stores, etc. This system underwent changes and at present the government procures the food grains for the food reserve and other requirement and the consumers are provided with a cash transfer system restricted only to needy (Zhou and Wan, 2006).

Bangladesh has a public food distribution system in place even before its Independence in 1971. This system has gradually changed from rationing system to public food distribution of today where bulk of the food is distributed through seven main channels school education programmes, Vulnerable Group Development, Vulnerable Group Feeding, Food for Work, Test Relief, Gratuitous Relief, and Food Assistance for Chittagong Hill Tribes Area. The government does procurement and stocking of the food grain only to level necessary to meet these programmes (Demeke et *al*., 2009; Ali et *al*., 2008). Similarly, Pakistan also has a rationing system since its independence and made changes in the system based on the time. Pakistan implements the programme through two government undertaking, namely The Pakistan Agricultural Storage and

Services Corporation (PASSCO) and Ghee Corporation of Pakistan (GCP). These parastatals procure wheat from the farmers at administered price and stock it. The distribution is through flour mills at subsided price (Salam and Mukhtar, 2008). Thailand has rice pledging prgramme from 2011 which provides a guaranteed price for the 3.7 million households (farmers). Under this scheme Thai government procure rice from poor framers at a US$ 420 above the market price (Morales, 2013).

Another well discussed and similar programme is implemented in Brazil known as Food Acquisition Programme which provides variety of food items to nearly 13 million people. Brazil also has a public procurement programme to ensure minimum returns to the farmers. It differs from PDS in terms underline supply chain. In Indian context the procurement is at national level from any producer for notified commodities namely, rice and wheat while the in Brazil it is a short supply chain where procurement is at local level. Procurement of commodities is done locally from family farmers. India distributes the food grains and other essential commodities nationally at subsidized rate while in Brazil distribution of the food is at local level through people's restaurants, community kitchens and food banks at almost zero cost. Additionally, Brazil has world's largest conditional cash transfer programme called as Bolsa *Família*. Even, Mexico provides conditional cash transfers along with other majors to improve food availabilities to its citizens. The major programmed named as Oportunidades was started in 2000. Under Oportunidades the cash transfer is done to the households on condition of making regular visit to the health clinic for preventive heath check-up and monthly attendance of nutrition and hygiene information sessions. Additionally cash transfer is provided based on the attendance of the school and increases with the school grades. (Demeke et *al*., 2009; Chmielewska and Souza, 2011; Souza and Chmielewska, 2011; Sharma and Gulati, 2012)

4. Food supply chain

The food supply chain is a complex multi-echelon chain with four tiers, namely, producers, processors/ distributors, retailers and customers (Lowe and Perckel, 2004; Kumar and Nigmatullin, 2011; Vajic *et al.*, 2012). This is a multi-disciplinary area that varies by product category, with a greater concentration on beef and potato chains. The studies are mainly based on developed countries such as Western Europe and North America. There are few studies in the agri-food supply chain in other parts of the world that have poor infrastructure and a localised food industry (Cunningham, 2001). Moreover, in developing countries, the main challenge for food supply chains is to integrate small and marginal farmers in terms of time and cost implications to the value adding supply chain (Ortmann, 2001).

Several studies (Higgins *et al*., 2010; Kumar and Nigmatullin, 2011; Vlajic *et al*., 2013) find that the food supply chain is characterised by the following:

- The presence of several participants of varying types and sizes
- A large variety of products
- The perishable nature of the product
- Demand uncertainty
- Seasonality in production
- Long production lead time due to the time lag between sowing and harvesting
- Disaggregation of material flow due to the large number of participants and the large assortments of products
- Decentralisation of the activities in the supply chain

The literature on food supply chains can be grouped in four categories.

- *Supply chain integration/coordination:* Work related to supply chain integration/ coordination indicates the need for faster transmission of information between members of the supply chain. This results in faster movement of the products and funds. In addition, the system will have reduced in transaction costs and increased in flexibility in terms of adjusting to changing consumer demands, economic conditions and technological improvement (Hobbs and Young, 2000; Ortmann, 2001). This aspect is covered in the following papers: Fritz and Hausen (2009), Hobbs and Young (2000), Kennett *et al,* (1998), Krejci and Beamon (2012), Lowe and Perckel (2004), Magnan (2011), Ortmann (2001), Sachan *et al.* (2005), Tsao *et al*. (2010) and Van der Vorst *et al,* (2000).
- *Risk management*: Risk management is an emerging area of study in food supply chains, because any disturbance in the functioning of the supply chain creates a shortage of food and also affects the quality of life. The major risks in food supply chain are product contamination and recall, loss of access – terrorism and protesters, loss of site, reduced capacity, loss of people and suppliers. (Dani and Deep, 2010; Deep and dani, 2009, Donnelly *et al.* 2012; Roth *et al.,* 2008). Studies in this area include Dani and Deep (2010), Deep and Dani (2009), Donnelly *et al.* (2012), Lowe and Perckel (2004) and *Roth et al.* (2008).
- *Sustainability:* Modern food supply chains insist on sustainability practices due to increasing pressure from stakeholders such as investors and buyers and to gain sustainable competitive advantages. Sustainability can be effectively implemented with a bilateral, collaborative approach. (Muller *et al.*, 2012) See Chkanikova and Mont (2012), Heikkurinen and Forsman-Hugg (2011) and Muller *et al.* (2012).

- *Cost reduction:* Costs in the supply chain can be lowered by reducing food wastage at different stages of the supply chain and rationalising the transportation policy, particularly in selecting the mode of transportation, routes, batching/grouping of products and transport schedules. See Ojha (2012), Parfitt *et al.* (2010), Sachan *et al.* (2005) and Tsao *et al*. (2010)

4.1. Modelling the food supply chain

The food supply chain needs to adopt advanced supply chain modelling practices similar to those of the manufacturing environment to handle the complexity in the chain. However, traditionally the food/agriculture supply chain has focused on addressing problems related to farm planning, crop rotation and optimisation of farm resources, leaving the area of distribution to retail (Ahumada and Villalobos, 2009). It lacks integrated models for the entire supply chain because of the high degree of complexity involved in developing and implementing integrated multi-echelon models (Ahumada and Villalobos, 2009; Higgins *et al*., 2010).

Traditional modelling tools such as linear programming, stochastic programming, risk programming, dynamic programming, stochastic dynamic programming and mixed integer programming fail to capture the complexity, dynamic, multi-faceted nature and data requirements for real-life representation of the multi-echelon food supply chain and therefore have limited applicability to model the entire value chain from farm to retail (Krejci and Beamon, 2012). At the same time, decision-makers in the food supply chain need a system that allows interaction between the actors, namely, farmers, traders, food processors, retailers and consumers. This needs a system with adaptive capacity in its operations, processes and flow coordination. The system needs to understand the behaviour of the members to particular

decisions and also needs to adjust to the physical state of the system based on a particular decision. This requires a tool with experimentation capacity to handle a distributed decision-making system (Hilletofth and Lattila, 2012; Labarthe *et al.* 2007). To make the system robust, it also needs to consider the dynamics of this supply chain, all its constituents and their coupling in the chain. It is necessary to have a system that can provide a method to analyse various alternatives so that decision-makers can quantify the gains from a particular alternative to make the right decisions (Swaminathan *et al.*, 1998).

4.2. Modeling of Supply Chains using Multi-Agent Systems

Multi-Agent Systems (MAS) can be used to model, monitor and manage a food grain supply chain because of its properties which can handle the dynamic, stochastic and multi-faceted nature of a food supply chain. It not only provides a holistic view of the system, but also considers the dynamic interaction between actors and their behaviour in the system. MAS are able to model heterogeneous, autonomous, intelligent and interacting agents, and the modularity of its architecture provides decision-makers with the flexibility to modify the models to their requirements (Barbati *et al.*, 2012; Hilletofth and Lattila, 2012; Krejci and Beamon, 2012; Rady, 2011; Swaminathan *et al.*, 1998). MAS helps in understanding the impacts of decisions on the entire supply chain by bring out actors that are significant. It helps in understanding different scenarios through experiments and what-if analyses. MAS is suitable for problems that have several problem-solving methods, multiple viewpoints and multiple entities. It can handle situations such as incomplete information and knowledge, distributed functionality, lack of a single global control, collaboration and coordination, and reconfiguration (Rady, 2011). It has capabilities to handle a large variety of problems compared to the classical optimisation method or heuristic methods. The problem-handling capabilities of MAS are summarised in Table 3.

Insert Table 3 about here

A typical MAS has three components (Macal and North, 2011)

- Agents, their attributes and behaviour
- Agent relationship and method of interaction (model architecture)
- Agents' environment

For further details refer to Macal and North (2011) and North and Macal (2007).

5. Methodology

MAS is suitable to map because of its properties which can able to handle the complexities present. Table 4 describes the complexities involved and the corresponding property of MAS.

Insert Table 4 about here

In this model, each entity (organisation) would be modelled as an agent. These agents would exchange material, information (messages) and/or money among themselves. The attributes related to these exchange processes would be parameters in the model; for example, during the purchase of food grain, farmers and purchase centres exchange food grain, which has attributes

such as quantities in tonnes, purchase price, and distance between the field and the purchase centre.

6. Mapping the PDS

The PDS system needs to be mapped in two parts, namely, procurement and distribution activities. This is due to the huge delay between procurement and distribution activities, the management and control activities at the central and state levels, the size of the operation and the number of participants involved in the supply chain. In this context, the first stage would be built to design the procurement and storage processes of the PDS system, which are largely managed by the FCI. In the second stage, the distribution process would be modelled. The output of the first stage would be input for the second stage. This two-stage model requires information such as the number of cardholders, their previous off-take of entitlement, buffer stock levels decided by the central government, stock position at various storage depots, and expected production of food grains from various organisations.

The overall structure of the proposed two stage models is shown in figure 2 and 3 below. The multi-agent system generates the trial solution and evaluates it for the optimal performance based on the performance indicators. This process is repeated till near optimal solution is achieved. In the following sub-sections we describe the working of the two multi-agent system based models.

Insert Figure 2 about here

Insert Figure 3 about here

6.1. Mapping the Procurement and Storage Process

6.1.1. Agents Involved

Farmers: These agents represent wheat or paddy producers who are willing to sell through the government purchase centre. Farmers decide quantities to be sold to the government-run purchase centres based on the prices declared by the agencies and the yield. They need to register themselves with government agencies. Registration contains details about the quantities available for sale, expected time of availability, location of the field, size of the land holding, irrigation facilities, etc. They also transport the food grain to the centre based on the schedule of their purchase at a particular purchase centre.

FCI/ State government agencies: These agents represent the agency responsible for purchase activities in a particular state. They are central controllers of the purchase centre. They decide the prices based on MSP and bonus so that farmers will be incentivised to sell their grain to the purchase centre. They open the registration of farmers. Based on the registration details, they verify the farmers' details and allocate a particular purchase centre along with the quantities that will be purchased during the purchase session. They also issue truck *challans* to transport food grain between the purchase centre and storage depots.

Purchase centre: These represent registered societies or centres run by the government/ FCI where purchasing activities are carried out. Based on the allocated farmers and the capacity of the centre, they prepare the purchase schedule and communicate it to the farmers. They physically verify the food grain brought by farmers to the purchase centre and approve it for the

purchase. They weigh and pack the approved grain in bags and issue a receipt to farmers for goods received. They raise transport indents to the FCI/state agencies based on stocks levels.

Third party transporter: These are transporters selected by government agencies to move food grain from the purchase centre to storage depots. Based on the truck *challans* issued, they arrange for the movement of food grain from the purchase centre to storage depots.

Storage depots: These are storage facilities owned by the FCI, CWC, State Warehousing Corporations (SWCs), state government or private owners. These depots report their available capacity before the procurement session begins to the FCI/state agencies. They receive the truckloads of food grain and stock them systematically for distribution.

6.1.2. Agent Interaction and environment

Agents interact with each other in an object-oriented manner where they exchange messages (information) and material (food grain). Figure 4 shows the interaction between agents (for the detailed interaction among individual agents, refer to Annexure I). The agents start their activities at the beginning of each purchase cycle. This functioning is restricted to the specific state of the country. There may be variations in the processes of interaction if the state/union territory changes.

Insert Figure 4 about here

6.2. Mapping the Distribution system

6.2.1. Agents Involved

Ministry of Consumer Affairs, Food and Public Distribution (MCAFPD): At the central government level, this organisation releases the allocation order every month based on the number of cardholders in each category in a particular state, the quantities demanded by the state and previous off-take figures of the state.

State Government Food and Civil Supply Department (SFACSD): At the state level, this organisation is responsible for the smooth functioning of the distribution system in the state. SFACSD sends its monthly requirements to the MCAFPD. It also does a district-wise allocation of the food grain.

District Food and Civil Supply Department (DFACSD): The district office of state civil supply corporation is responsible for distributing the food grain to fair price shops in the district. They identify beneficiaries and issue the appropriate ration card as per their eligibility. They also monitor fair price shops. They make payments to the FCI as per the issue price and actual take-off.

FCI Head Office (FCIHO): This central organisation decides the allocation plan for each state. It also decides the inter-state movement of food grain, management of buffer stocks, open market sales and exports/imports of food grain.

FCI Regional Office /sales office (FCIRO): It coordinates with the SFACSD for distribution of the food grain in the state/zone. They decide about the movement of food grain from different storage depots within the state/zone.

FCI Division/District Office (FCIDO): It controls and monitors the stocks in the storage depots and does the actual transfer from the FCI to the state for the final distribution to cardholders. The offices coordinate with the DFACSD for the movement of food grain to the FPS.

Storage depots: They are the link between the purchasing function and the distribution function. They manage the distribution of the food grain to the FPS according to the distribution plan given by the FCIDO/ DFACSD.

Fair Price shops (FPS): They are responsible for distributing the food grain to cardholders and they also maintain the issue details of each cardholder. They lift the stocks from the storage depots directly or through DFACSD. These shops are required to maintain the stocks and cardholder details for use by other agents.

Cardholders: The final purchase is done by cardholders from the FPS as per their eligibility.

6.2.2. Agent Interaction

Figure 5 shows the interaction between agents. (For the detailed interaction among individual agents, refer to Annexure II.)

6.2.3. Agent Environment

The process of distribution is a continuous process and works around the year. The MCAFPD, FCIRO and FCIHO prepare plans based on the national requirement, and other agents work as per the requirements of a specific state.

Insert Figure 5 about here

6.3. Discussion and Proposed improvement

The mapping is based on the present system and describes it as is. Based on the present system it is proposed to make changes in the policies followed by some of the agents. The changes will be made in polices related to the purchase frequency by the card holders, inventory policies at FPS and storage depots and procurement and storage strategies of the FCI. Scenarios will be generated based on these policy changes and compared with the present system. These comparisons will be helpful to address the non-optimal performance of these agents.

At present the purchasing is on periodic basic, the inventory policy followed is periodic review base stock policy and procurement and storage is concentrated in certain state. The purchase policy will be compared with daily purchase and random purchase. The inventory policy will be compared with (s, Q), (s, S), (R, S) and random inventory policies. The procurement policy will be compared with a local procurement policy as suggested by Murthy and Ramanayya (2007). This policy will ensure a certain minimum purchase at state level.

This comparison will help to make appropriate modifications in the present system. These modifications will be helpful to address the problems as discussed in section 2.1. These problems needs to be addressed because only 16% of the food subsidy reaches the targeted population (Kattumuri, 2011), about 3.81 lakh tones of non issuable stocks were with FCI in 2011-12 (annual report, department of food and public distribution, 2013, http://dfpd.nic.in/fcamin/annualreport/ann-2013-14.pdf) and procurement is cconcentred in the state of Punjab, Haryana, and Andhra Pradesh. Punjab and Haryana accounts for 63.12% of

wheat purchase in 2011-12 and AP, Chhattisgarh and Punjab accounts for 55.33 % of rice purchase in 2011-12.

7. Performance Measures

A supply chain performance measurement system is required to be in place for understanding effectiveness of the supply chain towards achieving its objectives. The supply chain needs to define appropriate performance indicators on all the important parameters which impact the service delivery such as inventory levels, order size, capacity and locations of the facilities, lead times, flexibility, etc. These performance indicators are based on the process characteristic and are helpful to measure the efficiency and effectiveness of the supply chain by comparing with the standards (Aramyan et *al*., 2007). To the best of our knowledge, the available literature only sites the performance of the PDS and other food security programmes in terms of food sufficiency, nutrient adequacy, cultural acceptability, safety, certainty and stability (Coates, 2013). It particularly measures income transfer to the poor (Jha and Ramaswami, 2010, 2011; Ramaswami, 2002), targeting errors (Ahluwalia, 1993; Khera, 2011; Mane, 2006; Ramaswami, 2002), price stabilizations effect (Cummings Jr., et *al*., 2010), pilferage control(Ahluwalia, 1993; Khera, 2011; Nagavarapuy and Sekhriz, 2011, 2012; Ramaswami and Balakrishnan, 2002), calorie intake and nutrition status (Jha et. *al*., 2011), implications on fiscal performance (Ramaswami and Balakrishnan, 2002), waste reduction (Parfitt, 2010), hunger status (Kattumuri, 2011) etc. This kind of performance measures may not be appropriate for the supply chain.

There are large numbers of performance indicators, proposed by the different researchers, available in published research relevant to supply chain domain. The combination of these indictors used in a particular performance management system depends on the context of the

research problem and underline industry/supply chain for which these are proposed. Hence, one needs to choose these indicators very carefully while designing their performance management system. Table 5 below presents an overview of performance indicators available in selective published research.

Insert Table 5 about here

The table above indicates that there are number of performance measures suggested for various supply chains. But these performance matrixes, such as measures based on the phases in the supply chain, balance score card, cannot be directly used for the PDS supply chain considering its characteristics, objectives and the problems present. Even the other performance matrixes which are based on the level of supply chain, PMS bottom line, Measuring Method, planning level needs modifications in their individual performance indicators so that it can be adopted for the PDS. Hence, we propose following performance measures relevant to the context. The proposed performance measurement system helps to estimate indictors at each stage of PDS supply chain.

The proposed quantitative performance indicators at each stage of the PDS supply chain are given below.

7.1. Performance Indicator for Purchasing

- Average quantity procured per day
- Average number of farmers processed per day

- Average number of days the purchasing centre works per purchase cycle
- Average distance travelled by grain bags from the purchase centre to the storage depot
- Number of trips made between the purchase centre and the storage depot

The first three indicators capture the efficiency of the purchase centres and also helps in deciding the required number of purchase centre and their capacities in the planning of next purchase cycle. The last two performance indicators capture the transportation cost during purchasing. This will help in optimising the transportation network for purchase and storage.

7.2. Performance indicators for storage:

- Average capacity of the storage depots
- Average inventory stocked at the storage depots
- Number of FPS served by a storage depot
- Average quantities moved between storage depots
- Average distance between two storage depots

The first three indicators help in improving efficiency of storage depots. These indictors will be the base for storage plan during the next purchase cycle. The last two indicators capture the inter-depots movement of the food grain. Optimising the performance on these indicators helps in reducing the transportation cost and the losses in the movement of the food grain and also minimises the handling and spoilage.

7.3. Performance indicators for distribution

- Average distance between the storage depot and the FPS

- Number of trips made between the storage depot and the FPS
- Average quantities purchased (take-off) per cardholder
- Average number of cardholders per FPS
- Average number of days' inventory stocked at the FPS

The first two indicators are related to the movement of food grain from storage depots to the FPS. An optimise performance on these indictors help in improving the cost and lead time performance of the system. The last three indicators measure the efficiency of the distribution system and also the service level to the customer.

These indicators will also help in addressing the problems as stated in section 2.1. This includes allocating the number of card holders per FPS. This can be done by estimating the average quantities purchased by the card holders. This further reduces the chances of black marketing by the agents. The average surplus can help in deciding the off take by the states'. Details of appropriate performance indicator for each problem are given in table 6 below.

Insert Table 6 about here

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8. Conclusion and Future Research

This paper identifies the major themes in the research on food supply chains as well as the problems and functioning of the PDS through a review of the literature. It proposes a two-stage model for mapping the PDS using MAS. The first stage maps the purchasing and storage

activities of the PDS, while the second stage maps the distribution process. The storage depots are the link between the two stages.

The modelling of the PDS will help government agencies improve their performance, so that the actors in the supply chain can develop their strategies for improving the food security situation.

The framework will help entities in the supply chains of products that involve various levels of functioning and also help members of the food supply chain where the government intervenes at various levels, because it highlights the interactions between the actors based on the processes in the system.

Future work:

The conceptual model will be implemented using factual data to suggest appropriate changes in the policy of purchasing, storage and distribution under the PDS. Further optimisation of the food grain inventories can be done for all actors in the supply chain. The base stock levels for each of the actors can be determined by finding the best combination of re-order points and order-up-level policies. This study can be conducted using discrete event simulation and meta-heuristics similar to Kapoor *et al*. (2014), which will help improve the performance indicators related to the stocks at each stage in the chain.

References:

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Annexure I: Interaction of Agents in Procurement and Storage process

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Insert Table 7 about here

Annexure II: Interaction between Agents at the Distribution Stage

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Insert Table 8 about here

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Figure 1: Presence of government in food grain supply chain

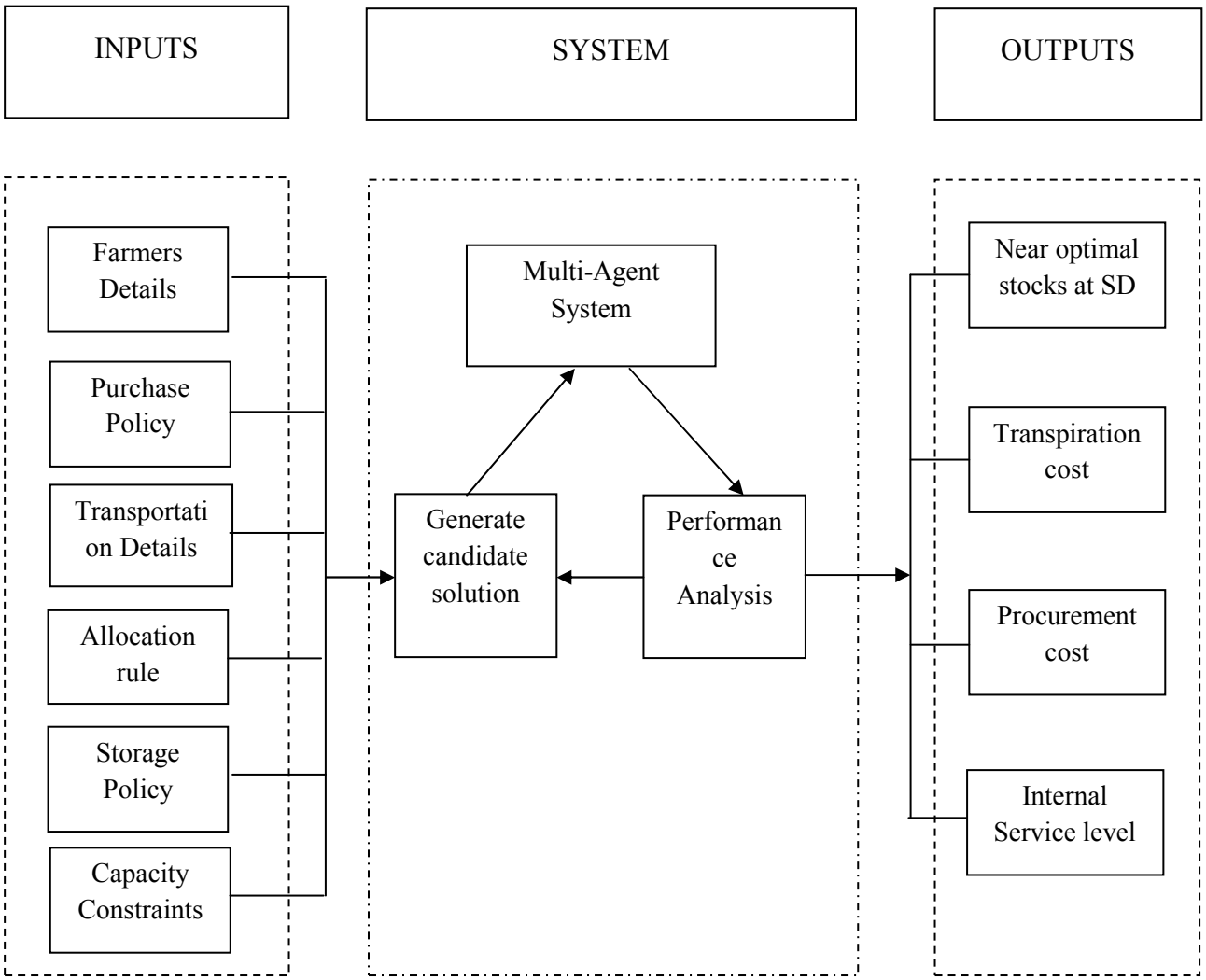

Figure 2, Structure of the Optimisation Framework for Procurement and Storage

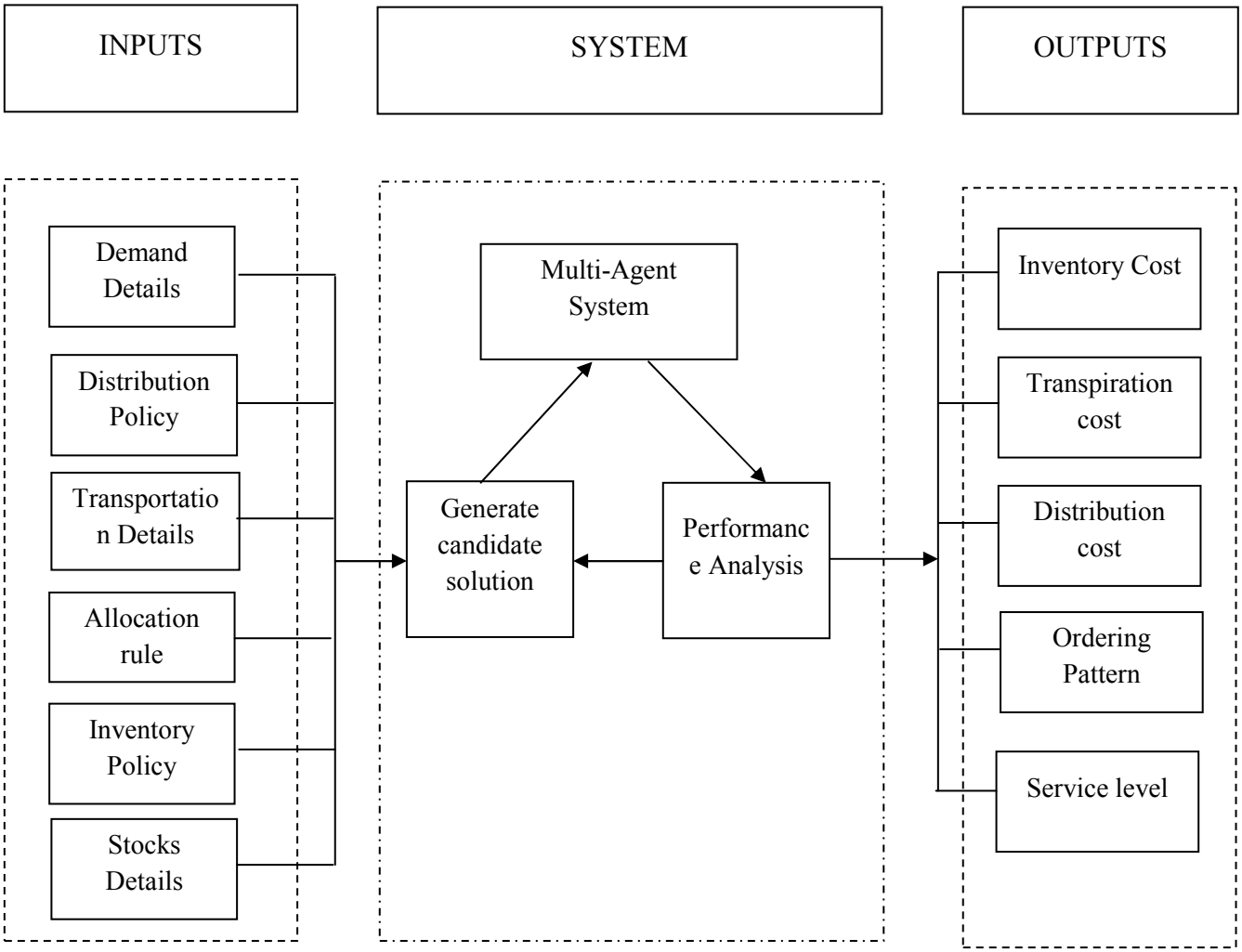

Figure 3, Structure of the Optimisation Framework for Distribution

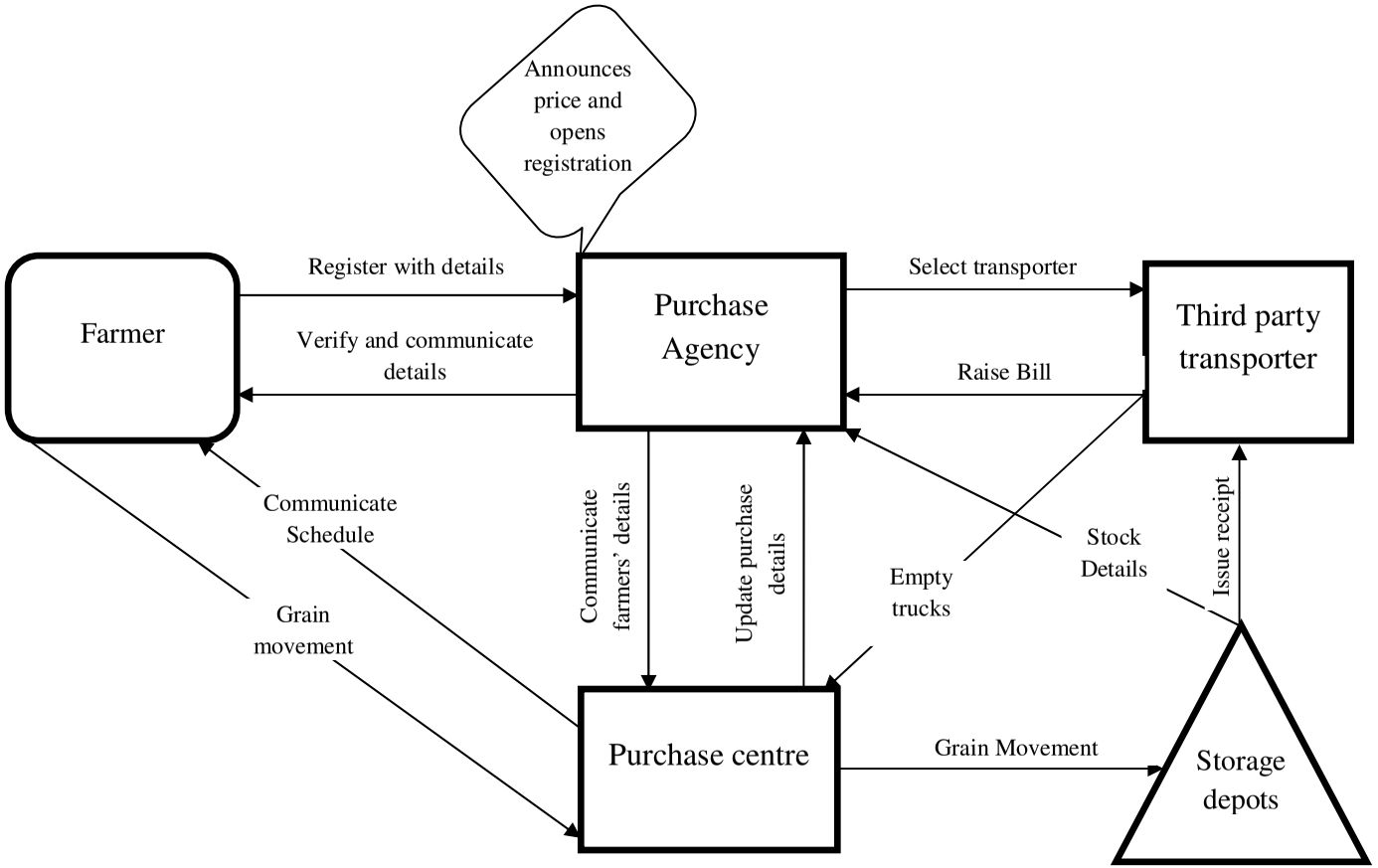

Figure 4, Interaction between Agents during Purchase

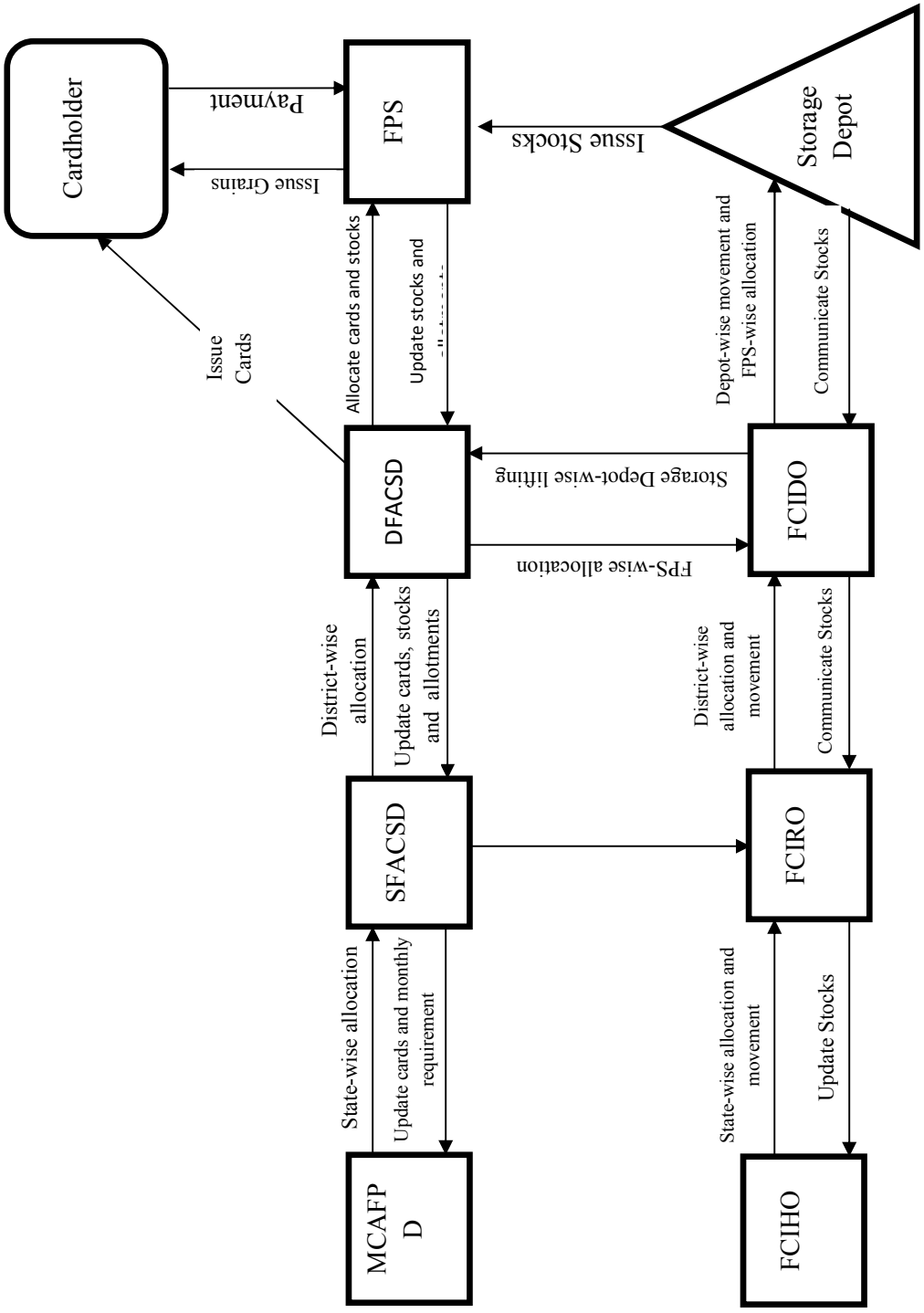

Figure 5, Interaction between Agents during Distribution

Table 1, Problem in the PDS

Problem	Causes	Effect	References
akages	High number of inclusion and exclusion errors; Black marketing	Needy people deprived from access to food	Swaminathan (2000); Ramaswami (2002); Mane (2006); Kattumuri (2011); Nagavarapuy and Sekhriz (2011, 2012)
Movement of food grain	Concentration of procurement activities in few states	Huge transportation costs, unnecessary payment of *mandi* (market place) fees to states where procurement takes place, losses and delays in transit and lack of control over monitoring of the stocks	Murthy and Ramanayya (2007)
Poor off-take by states	Allocation to the states is based on estimates of the number of BPL households rather than on actual purchases	States collecting less than what is allocated to them by the central government	Ramaswami (2002)
Excess cost	High administrative costs; lack of monitoring and control	Higher subsidy burden on the government	Jha and Ramaswami (2011)
Inactive participants	Credit problems; Distance between the shop and home; Non-availability of food grain during visits to the FPS; Incorrect or small variety of food grain stocks; Lack of awareness among cardholders about their entitled quantities; Malpractices at the	One-third of BPL cardholders do not purchase food grain from the PDS and half the BPL population does not purchase the full quota	Khera (2011); Nagavarapuy and Sekhriz, (2011, 2012)

	FPS; Incorrect inclusion in the BPL list		
ncentration certain ops	Price stabilisation mechanism developed through MSP	Excess stocks for reserved commodities and reduces the supply of other commodities	Ramaswami (2002)
or off-take open arket sales	Restrictions on the uses of procured food grain; High degree of bureaucracy at all stages; Absence of systematic mechanism for open market sales	Increased stocks with government	Ramaswami (2002); Basu (2011)
Speculation in the market	Large-scale procurement and subsequent selling under the open market scheme	Reduces private stocks and leads to higher prices for consumers in the open market; Uncertainty in managing the demand-supply gap	Ramaswami (2002)

Table 2, Food Security measure

Measure	Country
Maintenance of national food stocks (through public procurement or imports)	India; China; Brazil; Pakistan; Bangladesh; Ethiopia, Senegal, Cameroon, Pakistan, Cambodia, Iraq, Jordan, Lebanon, Malaysia, Nepal, Philippines, Republic of Korea, Thailand, Viet Nam, Yemen, Benin, Egypt, Eritrea, Kenya, Malawi, Mauritania, Nigeria, Senegal, Sierra Leone, Togo, Bolivia, Costa Rica, Dominican, Republic Guatemala, Guyana, Honduras
Public food distribution (includes targeted food distribution, food coupons, vouchers and school feeding)	India, Bangladesh, Cambodia, Ethiopia, Haiti, Liberia, Madagascar, Peru, Brazil, Burkina Faso, Cape Verde, China, Honduras, Kenya, Mexico, Mozambique, Dominican Republic, Egypt, Indonesia, Jordan, Lebanon, Mongolia, Morocco, the Philippines, Saudi Arabia, Afghanistan, Indonesia, Iraq, Jordan, Republic of Korea, Angola, Nigeria, Bahamas, Guatemala, Suriname
Cash subsidies (includes conditional cash transfer)	Brazil, Mexico, South Africa, Bangladesh, Indonesia, Jordan, Pakistan, Saudi Arabia, Yemen, Burkina Faso, Egypt, Ethiopia, Liberia, Mozambique, Chile, Costa Rica, Ecuador, El Salvador, Guyana, Haiti, Mexico, Suriname

(based on Demeke et *al*., 2009)

Table 3: Capabilities of Multi-Agent Systems

Parameter	**Multi-Agent Systems (MAS)**	**Classical Optimisation Techniques**
Size	Handle large-sized problems	Affect the solution time
Modularity	High	Some techniques may be parallelised
Time scale/Adaptability	React quickly	Relatively long time to respond
Solution quality	Poor quality	Higher quality
Computational stability	Robust due to ability to handle link failures	Not robust
Computation time	Low	Depends on size of the problem
Changeability	Relatively simple	Complete restart
Cost of communication	High	Low
Integrity	Supports integrity	Difficult to achieve

(Based on Barbati, et *al.*, 2012)

Table 4: Modelling Requirement and capacities of MAS

Model Requirement	MAS Capacity
Size of problem	Handle large-sized problems
Integration of actors	Supports integrity
Distributed Decision Making	Support High Modularity
Transparency	Understand the impacts of decisions on the entire supply chain so that it is improves visibility
Large number of Actors at different level of government functioning, public sector undertaking and private organizations	Model heterogeneous, autonomous, intelligent, and interacting agents
Multiple problem-solving methods, multiple viewpoints and multiple entities	Understand different scenarios through experiments and what-if analyses
Needs a system with adaptive capacity in its operations, processes and flow coordination	Relatively easy to change due to modular architecture

Table 5, Overview of Performance Indicators

Authors	Classification criteria	Category	Performance Indictors
Swaminathan *et al.*, (1998); Van der Vorst, (2005)	Level	Local	Inventory levels; Reliability and responsiveness to the deliveries; Firm level costs
		Global	Total supply chain cost; Product availability; Reliability of the delivery mechanism; Responsiveness
		Process	Responsiveness; Throughput time; Process yield; Process cost
Beamon (1998); Swaminathan *et al.*, (1998)	Measuring Method	Qualitative	Customer satisfaction; Flexibility; Integration of information and material flow; Effective risk management
		Quantitative	Cost minimisation; Profit maximisation; Fill-rate maximisation; Customer response time minimisation; Supplier reliability; Lead-time minimisation
Aramyan et al., (2007)	PMS Bottom lines	Efficiency	Cost (production, distribution, Transaction); Return on investments; profits; Inventory
		Flexibility	Customer satisfaction; Volume and delivery flexibility; Backorders; Lost sales
		Responsiveness	Fill rate; Product lateness; Customer response time; Lead time; Customer complaints; Shipping errors;
		Product quality	Sensory properties and shelf life; Product safety and health; Product reliability and convenience
		Process quality	Production system characteristics; Environmental aspects; Marketing
Gunasekaran et al., (2001); Gunasekaran et al., (2004); Gunasekaran and Kobu	Phases in supply chain	Plan	Product pricing and perceived value; return of investment; Labour efficiency; Time (Order lead, Total cash flow, Customer query); Cycle time (total, product development, bidding management); Compliance to regulations; Forecasting accuracy; Supply chain response time; Variances against budget; Net profit Vs productivity ratio; Accuracy of forecasting techniques; Information processing cost; Order entry methods;

(2007)		Source	Cost (obsolescence, inventory); Variety; Supplier (delivery performance, lead-time against industry norm, pricing against market, booking in procedures); Efficiency (purchase order cycle time, cash flow method)
		Make	Costs (obsolescence, overhead, inventory, operation hour); Value addition; Quality; Capacity utilization; Lead-time; Cycle time; Flexibility; Accuracy of scheduling; Range of products and services; Utilization of economic order quantity; Human resource productivity index
		Deliver	Cost (over head, inventory, stock-out, warranty, transportation); Reliability; Perceived value of product; Variety; Perceived quality; Flexibility of service system to meet customer needs; Effectiveness (enterprise distribution planning schedule, delivery); Invoice methods; Percentage of finished goods in transit; Quality of delivered goods; On time delivery of goods; Number of faultless delivery notes invoiced; Percentage of urgent deliveries; Information richness in carrying out delivery
Gunasekaran et al., (2001); Gunasekaran et al., (2004)	Planning Level	Strategic	Level of customer perceived value of product; Variances against budget; Time (Order lead time, Total cycle time, Total cash flow time, Product development cycle time); Information processing cost; Net profit Vs productivity ratio; Range of products and services; Flexibility of service system to meet customer needs; Effectiveness of enterprise distribution planning schedule
		Tactical	Time (customer query, product development cycle, planning process cycle); Accuracy of forecasting techniques; Order entry methods, Human resource productivity; Supplier (delivery performance, lead-time against industry norm, pricing against market, booking in procedures); Efficiency (purchase order cycle time, cash flow method); Percentage of defects; Cost per operation hour, Capacity utilization; Utilization of economic order quantity; Flexibility of service system to meet customer needs; Effectiveness (enterprise distribution planning schedule, delivery invoice methods); Percentage of finished goods in transit

		Operational	Order entry methods; Human resource productivity; Efficiency of purchase order cycle time; Supplier pricing against market; Percentage of defects; Cost per operation hour; Quality of delivered goods, On time delivery of goods; Effectiveness of delivery invoice methods; Number of faultless delivery notes invoiced; Percentage of urgent deliveries; Information richness in carrying out delivery; Delivery reliability performance
Bigliardi and Bottani (2010)	Balanced scorecard approach	Customer	Customer query time; Order lead time; Distribution lead time; Distribution performance; Delivery reliability, Effectiveness of distribution planning schedule; Quality of delivery goods; Flexibility of service system to meet customer needs; Customer perceived value of the product; Responsiveness to urgent delivery
		Internal processes	Purchase order cycle time; Effectiveness of master production scheduling; Supplier rejection rate; Total inventory cost; Frequency of delivery; Accuracy of forecasting technique; Planned process cycle time;
		Learning and growth	Suppler assistance in solving the problem; Supplier ability to respond quality problem; Buyer supplier collaboration; Order entry method; Level of Information sharing
		Financial	Information carrying cost; Supplier cost saving activities; Cost per operating hour; Return on investment; Variations against budget

Table 6, Problems and appropriate performance indicators

Problem	Performance Indicator
Leakages	Average quantities purchased (take-off) per cardholder Average number of cardholders per FPS
Movement of food grain	Average distance between the storage depot and the FPS Number of trips made between the storage depot and the FPS Average quantities moved between storage depots Average distance between two storage depots Average distance travelled by grain bags from the purchase centre to the storage depot Number of trips made between the purchase centre and the storage depot
Poor off-take by states	Average quantities purchased (take-off) per cardholder Average number of days' inventory stocked at the FPS Average number of cardholders per FPS Average inventory stocked at the storage depots
Excess cost	Average inventory stocked at the storage depots Number of FPS served by a storage depot Average quantities moved between storage depots Average distance between two storage depots Average distance between the storage depot and the FPS Number of trips made between the storage depot and the FPS Average quantities purchased (take-off) per cardholder Average number of cardholders per FPS Average number of days' inventory stocked at the FPS Average distance travelled by grain bags from the purchase centre to the storage depot Number of trips made between the purchase centre and the storage depot Average quantity procured per day

Speculation in the market	Average quantity procured per day Average number of farmers processed per day Average number of days the purchasing centre works per purchase cycle Average number of days' inventory stocked at the FPS Average inventory stocked at the storage depots Number of FPS served by a storage depot
Poor off-take in open market sales	Average capacity of the storage depots Average inventory stocked at the storage depots Number of FPS served by a storage depot Average quantities moved between storage depots Average distance between two storage depots

Table 7, Interaction of Agents in Procurement and Storage process

Agents	Interaction
Farmers and agencies	Agencies announce the purchase price of the food grain Agencies open the registration window for registration Farmers register themselves with the agencies Agencies check the registration information Agencies allocate a particular purchase centre and the approved quantities that would be purchased by the agencies.
Farmers and purchase centres	Purchase centre sends the schedule to the farmers Farmers arrive at purchase centre with the food grain as per the schedule and wait in the queue Purchase centre inspects the food grain Purchase centre accepts the food grain, weighs and packs for storage Purchase centre issues receipt to the farmers
Agencies and purchase centre	Agencies send the list of allocated farmers to the purchase centres Purchase centre updates the report of quantities purchased on a daily basis Purchase centre raises transport requirement for moving the grain from the purchase centre to storage depots Agencies send the copy of truck *challan* to the purchase centre Purchase centres update the status of food grain movement

Agencies and storage depots	Storage depots inform agencies about the capacity and stocks available Agencies send a copy of the truck *challan* to the storage depots indicating the quantities moved and the expected time of arrival Storage depots update the stocks after the trucks arrive
Agencies and third party transporter	Agencies call for quotations for the movement of food grain from the purchase centre to storage depots Third party transporters submit their quotes Agencies select the third party transporter Agencies issue the truck *challan* to the third party transporter The third party transporter raises the bill for payment based on receipts of goods received
Third party transporter and purchase centres	Third party transporter reports to purchase centre with empty trucks Purchase centre loads the truck and issues bill of material to the third party transporter Purchase centre updates the food grain movement
Third party transporter and storage depots	Third party transporter reports to the storage depot with truckloads Storage depots unload the trucks and issue a receipt of goods received to the trucker
Purchase centre and storage depots	Purchase centres move the food grain to storage depots Storage depots receive the food grain and unload it

Table 8, Interaction between Agents at the Distribution Stage

Agents	Interaction
Cardholders and FPS	Cardholders reach the FPS with their card FPS issues eligible quantity at final issue price to the cardholder and makes an entry in the card FPS updates the stocks and maintains the issue register
Cardholders and DFACSD	Cardholders apply for the card along with documents DFACSD verifies the documents and issues cards to the cardholders based on their eligibility
FPS and DFACSD	DFACSD assigns the cardholder to a particular FPS FPS updates the stocks and issues to the DFACSD FPS makes payment to the DFACSD based on quantities issued DFACSD makes allocation to the FPS based on the number of cardholders and previous stocks DFACSD updates the off-take figures
FPS and storage depots	Storage depots issue the food grain to the FPS as per allocation and then update the stock position
DFACSD and FCIDO	DFACSD issues an FPS-wise allocation plan to the FCIDO DFACSD makes payment to the FCIDO FCIDO issues a storage depot-wise lifting plan
DFACSD and SFACSD	DFACSD reports the monthly off-take to the SFACSD DFACSD updates the details of cardholders to the SFACSD

	SFACSD issues a district-wise issue plan based on DFACSD reports SFACSD issues any special allocation plans
SFACSD and FCIRO	SFACSD communicates the district-wise allocation/lifting plan to the FCIRO
SFACSD and MCAFPD	SFACSD updates the status of cardholders (number of cardholders in each category, additions and deletions, if any) to MCAFPD SFACSD communicates the monthly requirement to the MCAFPD MCAFPD updates the requirement and issues a state-wise allocation
MCAFPD and FCIHO	MCAFPD issues a state-wise allocation plan to the FCIHO
FCIHO and FCIRO	FCIRO updates the stock position within the region FCIHO communicates the state-wise allocation plan FCIHO issues the movement order to move the food grain from one region to another
FCIRO and FCIDO	FCIDO updates the stocks available in the district to the FCIRO FCIRO issue a district-wise allocation order to the FCIDO and the movement plan between the districts
FCIDO and Storage Depots	Storage depots update the stock positions to the FCIDO FCIDO provides the depot-wise movement plan and the FPS-wise lifting plan