Modelling of Supply Chain of Rice Milling Systems in Bangladesh 11

In the previous chapters, case studies on system dynamics modelling of boom and bust of cocoa production systems in Malaysia, modelling of hilsa fish population in Bangladesh and modelling of food security in Malaysia have been presented. This chapter presents the application of system dynamics modelling to supply chain of rice milling systems to demonstrate how to construct system dynamics models and simulate these models for policy planning and design. The model presented is an illustration of modelling and simulation of practical problem to provide management scenarios and policy options, and such experiences are essential to face the challenge of modelling and simulation of dynamic systems in practice. To achieve these goals, the model of this case study is organised as follows: (1) introduction, (2) dynamic hypothesis, (3) causal loop diagram, (4) stock–flow diagram, (5) model validation, (6) simulation and policy analysis and (7) conclusion. The model is simulated to address supply chain management scenarios and design the policy options for efficient and sustainable supply chain management of rice milling systems in Bangladesh to ensure the availability of rice to the consumers in an economic manner under uncertainty. The model has the potential to identify and study the critical components of the overall supply chain, allowing for the creation of an efficient and sustainable network.

11.1 Introduction

Rice is the staple food grain in Bangladesh, and it covers almost three quarters of the total cropped area in Bangladesh. Per capita consumption of rice in Bangladesh is one of the highest in the world and it is 188 kg (BBS 2011). The production of rice in Bangladesh has increased significantly over last 40 years, and this success has been strongly related to high yielding varieties triggered by the liberalisation of key input markets such as irrigation and fertilisers (Ahmed 2000; Hossain 1988; Hossain et al. 2006). Although rice production has increased in the recent years with a self-sufficiency in rice food security, the availability of rice to consumers has

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not been stabilised, and hence the changes in the price of rice by days and even by minutes have been common phenomenon. This indicates that it is necessary to identify the appropriate demand and meet them properly in a profitable way, and it is the primary concern of rice supply chain. A proper supply chain management framework is very essential for efficient sourcing, processing, distribution and retailing and hence meeting the customer demands without facing any crisis. Production and business of rice have been one of the most traditional and major concerns of milling industries in Bangladesh. But still no proper supply chain framework has been developed. Of course, dealing with inventory is the major issue in the supply chain management of rice, and it requires that milling, wholesale and retail inventories are properly managed and maintained to ensure the availability of rice to the consumers.

Rice supply chain in Bangladesh is a focus for considerations of food security and climate change impacts. The rice supply chain in Bangladesh is demand driven. Although Bangladesh is self-sufficient in rice, the supply chain does not meet the requirement at the right time at the right place resulting artificial crisis and price volatility. Furthermore, the supply of paddy is also affected by natural calamities such as drought and flood. This requires the supply chain to be more demand driven and all the actors involved in the supply chain to be responsive to the demand information of the ultimate consumers in a timely and cost-effective manner.

Realisation of a demand-driven supply chain is a complex task (Selen and Soliman 2002). Any consumer requirement may trigger execution of different activities by different contributors (Prahalad and Ramswamy 2000), and hence demand-driven supply chains are highly dynamic having different modes of cooperation, control and coordination. This requires that demand-driven supply chains must be modelled and simulated before implementation. Reference process models can be valuable means to support these challenges in the design and implementation of demand-driven supply chains. The reference process models represent specific ordering work activities across time and place (Verdouw et al. 2010; Davenport 1993). Reference process models are predefined models used for the construction of other models (Verdouwa et al. 2010; Thomas 2006). Also the reference process models can be used to construct system dynamics computer models using systems approach developed by Forrester (1968).

Rice milling systems in Bangladesh mainly consist of milling sector, wholesale sector and retail sector. The milling sector procures paddy from the farmers, paddy traders and wholesalers and then prepares the milled rice. The wholesale sector procures the milled rice from this sector and sells the milled rice to the retail sector, while the retail sector sells the milled to the consumer. The product turnover of the retailers is about 22 kg per day. This compares with 10 tons per day for the wholesalers and up to 50 tons per day per mill. In other words, an urban retailer would need on average the sales of 1.5 farmers to assure his rice supplies for the year, whereas a wholesaler would require the sales of 400 farmers and a mill about 2000 farmers (Minten et al. 2013). The supply of paddy to milling sector is seasonal, and there are three seasons of rice production. The main harvesting season is from November to January followed by April to June and July to August. The demand of milled rice to the retail sector depends on the per capita rice consumption and population level. The critical components are supply of paddy in the milling sectors and inventory in the milling, wholesale and retail sector as well as the supply chain costs. Effective management requires timely delivery of rice at right quantity at the right time and right place. The current supply chain of rice milling systems in Bangladesh is lacking efficiency, and this needs reforms. This necessitates a computer model to analyse and support the rice milling systems in Bangladesh. However, for sustainable development of rice supply system in Bangladesh, rice supply chain management must be modelled and simulated for designing policy options before implementation (Bala 1999).

Carter and Easton (2011) reported a systematic review of sustainable supply chain management and demonstrated that it is necessary to develop models. Riddals et al. (2000) reported a critical review of the various mathematical methods used to model and analyse supply chains and concluded that operations research techniques are useful in providing solutions to local tactical problems, but the impact of these solutions on the global behaviour of the whole supply chain can only be assessed using dynamic simulation. System dynamics techniques, a methodology of constructing dynamic simulation model based on feedback concepts incorporating non-linearities and time lags developed by Forrester can be used to model such a dynamic system and analyse performance dynamics of the system (Bala 1999; Forrester, 1968).

Several studies have been reported on system dynamics modelling of supply chain of food industry (Apaiah et al. 2005; Apaiah and Hendrix 2005; Georgiadis et al. 2005). Minegishi and Thiel (2000) developed a system dynamics supply chain model to study the complex logistic behaviour of an integrated food industry and applied it to poultry production and processing to study the influence of different policies like the poultry breeding program and to show the phenomena of instabilities and system controls in supply chains confronted with serious hazards. Vo and Thiel (2008; 2011) reported dynamic behaviour of the entire chicken meat supply chain under bird flu crisis during the period from October 2005 to March 2006 in France, and this model is helpful to decision-makers for other fresh food supply chains when they are facing such crises. Kumar and Nigmatullin (2011) reported a system dynamics model to study the non-perishable product food supply chain performance under a monopolistic environment, and the model was used to study the behaviour and relationships within a supply chain for a non-perishable product and to determine the impact of demand variability and lead time on supply chain performance. The proposed model can be used to analyse 'what if scenarios' of different inventory policies and strategic food supply chain management issues. Also Sachan et al. (2005) reported a system dynamics model of Indian grain supply chain cost to device policies to reduce total supply chain cost and suggested action plans to reduce total supply chain costs.

Several studies have been reported on modelling of food supply chain management (Bosona and Gebresenbet 2013; Dabbene et al. 2008a, b). Dabbene et al. (2008a, b) reported a hybrid model consisting of event-driven dynamics and time-driven dynamics to describe beef meat supply chain, and Bosona and Gebresenbet (2013) conducted route analysis to determine optimal product centres of local food chain. Vo and Thiel (2011) reported an economic simulation of poultry supply chain using system dynamics. More recently detailed frameworks of food supply chain assessment and reference process models for sustainable food supply chain have been reported (Manzini and Accorsi 2013; Verdouw et al. 2010). Although Sachan et al. (2005) reported a system dynamics grain supply chain cost model, it does not include grain supply chain management. Effective and sustainable supply chain management of rice milling systems should not only consider total supply chain cost but also should consider inventory decision and policy development for effective and sustainable management of rice milling systems. To meet this research and literature gap as well the research gap, Bala et al. (2015) and Bhuiyan (2015) motivated us to develop a system dynamics model of rice milling systems that focuses on inventory and policy development. The modelling of the supply chain of the rice milling systems presented here is adopted from Bala et al. (2015) and Bhuiyan (2014).

11.2 Dynamic Hypothesis

The dynamic hypothesis seeks to define the critical feedback loops and stock–flow diagrams that drive the system's behaviour in the reference mode. When the model based on feedback concept is simulated, the endogenous structure of the stock–flow diagram should generate the reference mode behaviour of the system, and thus the endogenous structure causes the changes in dynamic behaviour of the system. In system dynamics modelling, causal loop diagrams and stock–flow diagrams are hypothesised to generate the reference mode of the behaviour over time (Sterman 2000). Supply chain of rice milling systems can be represented by causal loop diagrams and stock–flow diagrams, and the simulation model based on the causal loop diagram and stock–flow diagram would generate dynamic behaviour of the supply chain of the rice milling systems. The supply chain of rice milling systems in the form of causal loop diagram and stock–flow diagram is hypothesised to generate the observed inventory and price in the reference mode. In essence the bullwhip effect in the inventory levels results from the endogenous consequences of the feedback structure of the system.

11.3 Causal Loop Diagram

The causal loop diagram of the supply chain of rice milling systems in Bangladesh is shown in Fig. 11.1. The daily retailer demand is computed from the per capita consumption and population. When the inventory of the retailer reaches the reordering point, the retailer places order to the wholesaler which is equal to economic order quantity. The wholesaler also places order at the reordering point, and the quantity ordered is the economic order quantity. The miller procures the paddy from the farmers, the paddy traders and wholesalers. The rice production is seasonal. The supply chain of the rice milling systems shown in Fig. 11.1 is a multi-loop system having some non-linear cause–effect relationships. For example, three major loops of the milling sector are milling–order for milling–rice inventory–rice for milling–milling; milling–reordering point for milling–milling; and milling–rice for wholesale–wholesale–order for wholesale–milling. Also

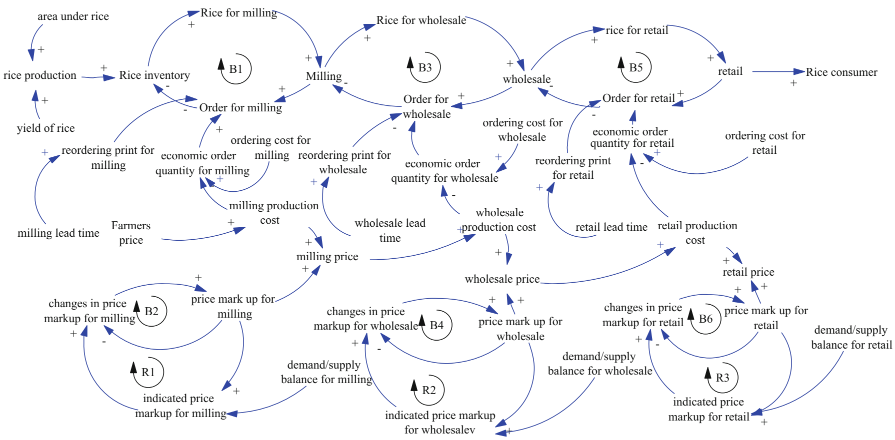

Fig. 11.1 Causal loop diagram of supply chain of the rice milling systems in Bangladesh

demand/supply balance is non-linearly related to price markup. Wholesale and retail also have similar multi-loops and non-linearities.

An economic order quantity could assist in deciding what would be the best optimal order quantity at the lowest cost. Similar to economic order quantity, the reordering point will advise when to place an order for specific products based on the historical demand. The reordering point also allows sufficient stock at hand to satisfy demand while the next order arrives due to the lead time.

The economic order quantity is computed using the following equation (Riggs 1970):

$$Q = \sqrt{\frac{2DS}{H}} \tag{11.1}$$

where

$Q =$ economic order quantity of rice, tons
$D =$ annual demand of rice, tons
$S =$ ordering cost, taka/tons
$H =$ holding and storage cost, taka/ton

and the reordering point for the economic order quantity is computed from the following equation (Riggs 1970):

$$R = d \times L + z \times \sigma_L \times \sqrt{L} \tag{11.2}$$

where

$R =$ reordering point, tons
$d =$ average demand of rice, tons per day

L = lead time, day
z = safety factor
σ_L = standard deviation of average demand, ton

The economic order quantity model gives an optimal solution in closed form, and this model has been effectively employed in automobiles, pharmaceutical industries and retail sectors (Muckstadt and Sapra 2010). Another important technique used along with economic order quantity is the reordering point and safety stock, and this reflects the level of inventory that triggers the placement of an order for another units, whereas the quantity associated with safety stock protects from stock-out (Chen 1998).

The milling price, wholesale price and retail price are determined in this study by change in price markup anchored by demand/supply balance (Kpmaier and Voigt 2013; Teimoury, et al. 2013).

11.4 Stock–Flow Diagram

The detailed STELLA flow diagram of the rice milling systems in Bangladesh is shown in Fig. 11.2. In this study, we consider the simulation of inventories of rice in the milling systems for economic order quantities and different policy options for sustainable optimum operation of the rice milling systems in Bangladesh. The fundamental equations used in this study are as follows.

11.4.1 Rice Milling Sector

Rice inventory is increased by rice production and decreased by sales for milling, and it is computed as

$$\begin{aligned}\text{rice inventory } (t) = \text{rice inventory } (t-1) + \text{rice production rate} \times \Delta t \\ -\text{rice sales for milling} \times \Delta t\end{aligned} \tag{11.3}$$

Rice production depends on area under rice cultivation and yield of rice, and it is calculated as

$$\text{rice production rate} = \text{area under rice} \times \text{yield of rice} \tag{11.4}$$

The rice sales for milling is equal to milling order rate for rice for milling on order and milling received for milling inventory. It is the actual milling placed. When milling on order plus milling inventory is less than milling reordering point, then milling placed is milling reordering point; otherwise, it is zero. This is expressed as

$$\text{milling placed} = \text{IF}(\text{milling on order } + \text{milling inventory}) < (\text{milling reordering point})\text{THEN}(\text{milling to order})\text{ELSE}(0) \tag{11.5}$$

Milling reordering point is defined as the milling demand average over milling lead time plus milling safety stock, and it is computed as

$$\text{milling reordering point} = (\text{milling demand aver} \times \text{milling lead time }) + \text{milling safety stock} \tag{11.6}$$

The safety stock for milling is computes as

$$\text{milling safety stock} = \text{milling safety factor} \times \text{standard deviation of milling demand aver} \times \text{SQRT}(\text{milling lead time}) \tag{11.7}$$

Milling to order, i.e. milling reordering point, is initiated when milling inventory is less than milling reordering point; otherwise, it is zero. This is expressed as

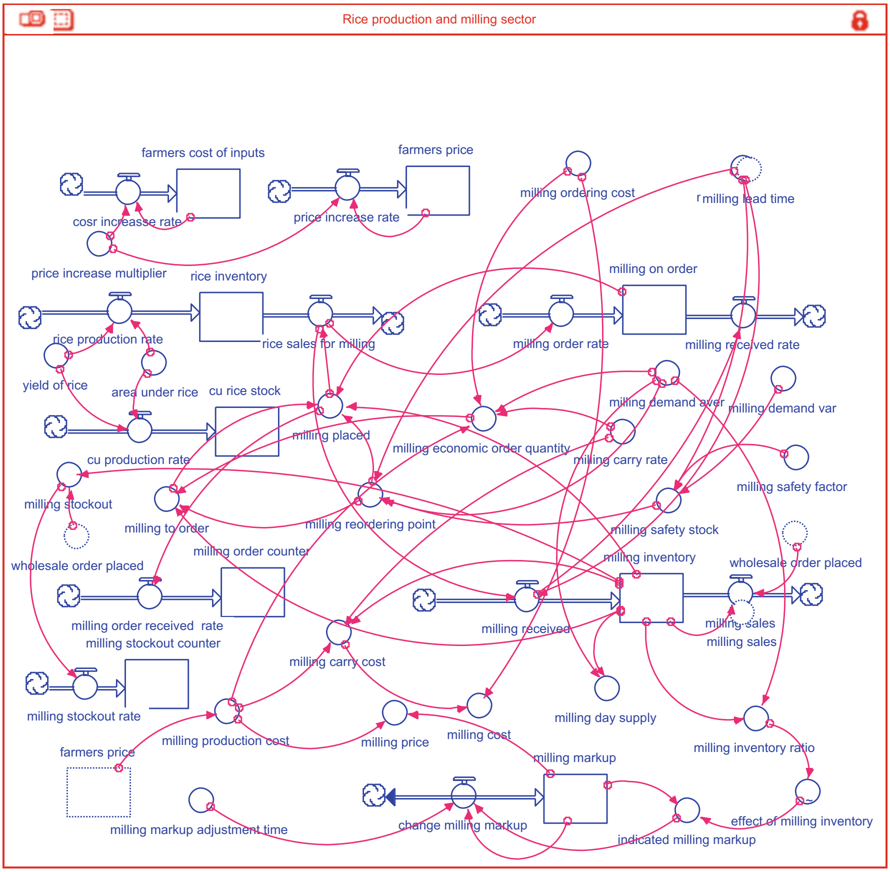

Fig. 11.2 STELLA flow diagram of the rice milling systems in Bangladesh

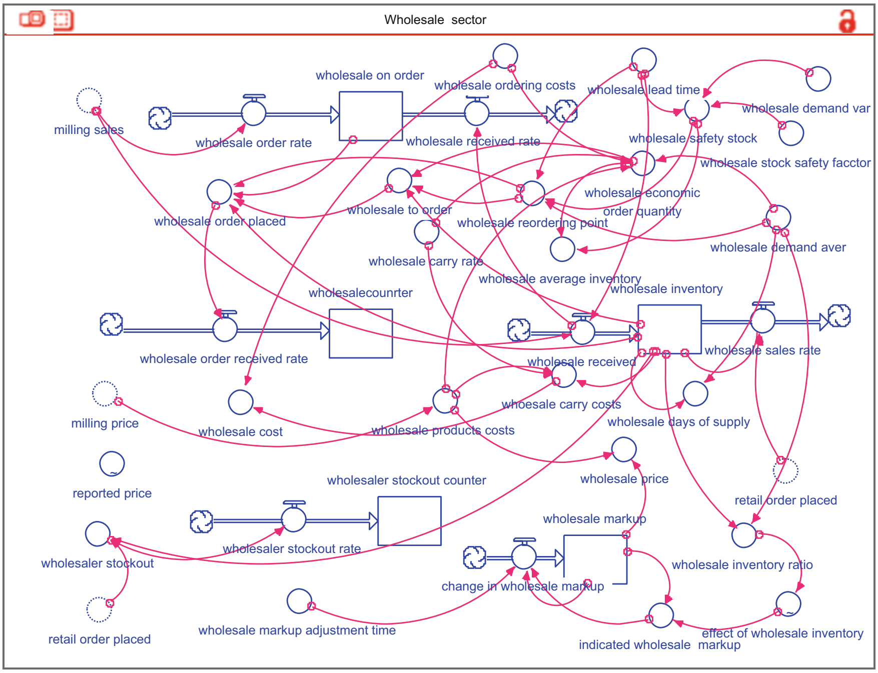

Fig. 11.2 (continued)

$$\text{milling to order} = \text{IF(milling inventory)} < \text{(milling reordering point)THEN(milling economic order quantity)ELSE}(0) \tag{11.8}$$

Milling economic order quantity is computed from the following relation:

$$\begin{aligned}&\text{milling economic order quantity}\\&= \text{SQRT}\big((2 \times \text{milling demand aver} \times \text{milling ordering cost})\\&/((\text{milling carryrate}/365) \times \text{milling production cost})\big)\end{aligned} \tag{11.9}$$

The state variable milling on order is increased by milling order rate and decreased by milling received rate by milling inventory, and it is computed as

$$\text{milling on order}(t) = \text{milling on order } (t-1) + \text{milling order rate} \times \Delta t - \text{milling received rate} \times \Delta t \tag{11.10}$$

Rice milling inventory is increased by milling received and decreased by milling sales of rice, and it is expressed as

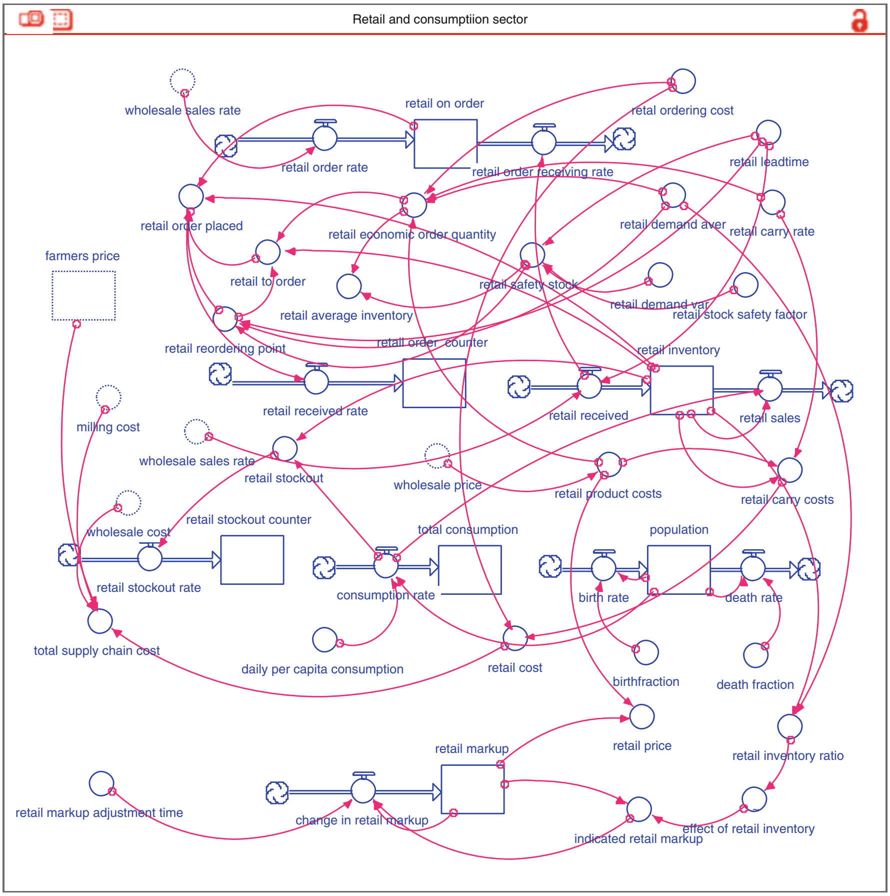

Fig. 11.2 (continued)

$$\text{milling inventory }(t) = \text{ milling inventory }(t-1) \; + \text{milling received} \times \Delta t \\ -\text{milling sales} \times \Delta t \tag{11.11}$$

Milling received is the rice received for milling in the milling inventory with a time delay of milling lead time, and it is expressed as

$$\text{milling received} = \text{DELAY}(\text{rice sales for milling}, \text{milling lead time})) \tag{11.12}$$

Milling sales depends on milling inventory and wholesale order placed. When wholesale order placed is greater than milling inventory, then milling sales is equal to milling inventory; otherwise, it is wholesale order placed, and it is expressed as

$$\text{milling sales} = \; \text{IF}(\text{wholesale order placed}) > (\text{milling inventory}) \\ \times \text{THEN}(\text{milling inventory})\text{ELSE}(\text{wholesale order placed}) \tag{11.13}$$

The milling price of rice is computed from cost of milled rice and price markup for milling as

$$\text{milling price} = \text{MAX}\big(\text{milling production cost}\ ,\ (1 + \text{milling markup}) \times \text{milling production cost}\big) \tag{11.14}$$

Price markup for milling of rice depends on change in milling markup, and it is computed as

$$\text{milling markup}(t) = \text{milling markup}(t-1) + \text{change in milling markup} \times \Delta t \tag{11.15}$$

Change in milling markup depends on milling markup itself, indicated milling markup and milling markup adjustment time, and it is computed as

$$\text{change in milling markup} = (\text{indicated milling markup} - \text{milling markup}) / \text{milling markup adjustment time} \tag{11.16}$$

Indicated price markup for milling of rice is computed from price markup for milling and effect of relative inventory coverage of the milled rice (Sterman 2000; Teimoury et al. 2013), and it is computed as

$$\text{indicated milling markup} = \text{milling markup} \times \text{effect of milling inventory} \tag{11.17}$$

Effect of milling inventory is expressed as a non-linear graphical function of relative inventory coverage of the milled rice. This formulation of price settling essentially consists of expectation adjustment and price adjustment (Sterman 2000). The concept of expectation adjustment was introduced by Nerlove (1958), and subsequently it was used by Meadows (1970) and Bala (1975, 1990) for formulation price setting of agricultural commodities with a reasonably good agreement between the predicted prices and reported values.

11.4.2 Wholesale Sector

Wholesale on order is increased by wholesale order rate and decreased by wholesale received rate, and it is computed as

$$\text{wholesale on order}(t) = \text{wholesale on order}\ (t-1) + \text{wholesale order rate} \times \Delta t - \text{wholesale received rate} \times \Delta t \tag{11.18}$$

Rice wholesale inventory is increased by wholesale received and decreased by wholesale sales rate of rice, and it is expressed as

$$\text{wholesale inventory }(t) = \text{ wholesale inventory }(t-1) + \text{wholesale received} \times \Delta t \\ -\text{wholesale sales rate} \times \Delta t \tag{11.19}$$

Wholesale received is the rice received for wholesale inventory with a time delay of wholesale lead time, and it is expressed as

$$\text{wholesale received} = \text{DELAY}(\text{milling sales, wholesale lead time}) \tag{11.20}$$

Wholesale sales rate depends on wholesale inventory and retail order placed. When retail order placed is greater than wholesale inventory, then wholesale sales rate is wholesale inventory; otherwise, it is retail order placed, and it is expressed as

$$\text{wholesale sales rate} = \text{IF}(\text{retail order placed}) \\ > (\text{wholesale inventory})\text{THEN}(\text{wholesale inventory})\text{ELSE}(\text{retail order placed}) \tag{11.21}$$

When wholesale on order plus wholesale inventory is less than wholesale reordering point, then wholesale order placed is wholesale to order; otherwise, it is zero. This is expressed as

$$\text{wholesale order placed} = \text{IF}(\text{wholesale on order } + \text{wholesale inventory}) \\ < (\text{wholesale reordering point})\text{THEN}(\text{wholesale to order})\text{ELSE}(0) \tag{11.22}$$

Wholesale reordering point is defined as the sum of wholesale demand average over wholesale lead time and wholesale safety stock, and it is computed as

$$\text{wholesale reordering point} = (\text{wholesale demand aver} \times \text{wholesale lead time }) \\ +\text{wholesale safety stock} \tag{11.23}$$

The safety stock for wholesale is computes as:

$$\text{wholesale safety stock} = \text{wholesale safety factor} \\ \times\text{standard deviation of wholesale demand aver} \times \text{SQRT}(\text{wholesale lead time}) \tag{11.24}$$

Wholesale to order, i.e. wholesale reordering point, is initiated as wholesale economic order quantity. When wholesale inventory is less than wholesale reordering point, then wholesale to order is wholesale economic order quantity; otherwise, it is zero. This is expressed as

$$\text{wholesale to order} = \text{IF}(\text{wholesale inventory}) < (\text{wholesale reorderingpoint})\text{THEN}(\text{wholesale economic order quantity})\text{ELSE}(0) \tag{11.25}$$

Wholesale economic order quantity is computed from the following relation:

$$\text{wholesale economic order quantity} = \text{SQRT}\big((2 \times \text{wholesale demand aver} \times \text{wholesale ordering cost})/((\text{wholesale carry rate}/365) \times \text{wholesale product cost})\big) \tag{11.26}$$

The wholesale price of rice is computed from cost of wholesale rice and price markup for wholesale as

$$\text{wholesale price} = \text{MAX}\big(\text{wholesale productscosts}\ ,\ (1 + \text{wholesale markup}) \times \text{wholesale products cost s}\big) \tag{11.27}$$

Price markup for wholesale of rice depends on change in wholesale markup, and it is computed as

$$\text{wholesale markup}(t) = \text{wholesale markup}(t-1) + \text{change in wholesale markup} \times \Delta t \tag{11.28}$$

Change in wholesale markup depends on wholesale markup itself, indicated wholesale markup and wholesale markup adjustment time and it is computed as

$$\text{change in wholesale markup} = (\text{indicated wholesale markup} - \text{wholesale markup}) / \text{wholesale markup adjustment time} \tag{11.29}$$

Indicated price markup for wholesale of rice is computed from price markup for wholesale and effect of relative inventory coverage of the wholesale rice (Sterman 2000; Teimoury et al. 2013), and it is computed as

$$\text{indicated wholesale markup} = \text{wholesale markup} \times \text{effect of wholesale inventory} \tag{11.30}$$

Effect of wholesale inventory is expressed as a non-linear graphical function of relative inventory coverage of the wholesale rice.

11.4.3 Retail Sector

Retail on order is increased by retail order rate and decreased by retail received rate, and it is computed as

$$\text{retail on order}(t) = \text{retail on order } (t-1) + \text{retail order rate} \times \Delta t \\ -\text{retail received rate} \times \Delta t \tag{11.31}$$

Rice retail inventory is increased by retail received and decreased by retail sales of rice, and it is expressed as

$$\text{retail inventory } (t) = \text{retail inventory } (t-1) + \text{retail received} \times \Delta t \\ -\text{retail sales} \times \Delta t \tag{11.32}$$

Retail received is the rice received for retail inventory with a time delay of retail lead time, and it is expressed as

$$\text{retail received} = \text{DELAY}(\text{wholesale sales, retail lead time}) \tag{11.33}$$

Retail sales rate depends on retail inventory and consumption rate. When consumption rate is greater than or equal to retain inventory, then it is retail inventory; otherwise, it is consumption rate, and it is expressed as

$$\text{retail sales} = \text{IF}\big(\text{consumption rate} \\ >= \text{retail inventory}\big)\text{THEN}(\text{retailinventory})\text{ELSE}(\text{consumption rate}) \tag{11.34}$$

When retail on order plus retail inventory is less than retail reordering point, then retail placed is retail to order; otherwise, it is zero. This is expressed as

$$\text{retail placed} = \text{IF}(\text{retail on order } + \text{retail inventory}) \\ < (\text{retail reordering point})\text{THEN}(\text{retail to order})\text{ELSE}(0) \tag{11.35}$$

Retail reordering point is defined as the sum of retail demand average over retail lead time and retail safety stock, and it is computed as

$$\text{retail reordering point} = (\text{retail demand aver} \times \text{retail lead time }) \\ +\text{retail safety stock} \tag{11.36}$$

The safety stock for retail is computed as

$$\text{retail safety stock} = \text{retail safety factor} \\ \times\text{standard deviation of retail demand aver} \times \text{SQRT}(\text{retail lead time}) \tag{11.37}$$

Retail to order, i.e. retail reordering point, is initiated as retail economic order quantity. When retail inventory is less than retail reordering point, then retail to order is retail reordering quantity; otherwise, it is zero. This is expressed as

$$\text{retail to order} = \text{IF}(\text{retail inventory}) \\ < (\text{retail reorderingpoint})\text{THEN}(\text{retail economic order quantity})\text{ELSE}(0) \tag{11.38}$$

Retail economic order quantity is computed from the following relation:

$$\text{retail economic order quantity} = \text{SQRT}\big(\big(2 \times \text{retail demand aver} \times \text{retail ordering cost}\big)/\big((\text{retail carry rate}/365) \times \text{retail product cost}\big)\big) \tag{11.39}$$

The retail price of rice is computed from cost of retail rice and price markup for retail as

$$\text{retail price} = \text{MAX}(\text{retail productcosts}\ ,\ (1 + \text{retail markup}) \times \text{retail product cost s}) \tag{11.40}$$

Price markup for retail of rice depends on change in retail markup, and it is computed as

$$\text{retail markup}(t) = \text{retail markup}(t-1) + \text{change in retail markup} \times \Delta t \tag{11.41}$$

Change in retail markup depends on retail markup itself, indicated retail markup and retail markup adjustment time, and it is computed as

$$\text{change in retail markup} = (\text{indicated retail markup} - \text{retail markup}) / \text{retail markup adjustment time} \tag{11.42}$$

Indicated price markup for retail of rice is computed from price markup for retail and effect of relative inventory coverage of the retail rice (Sterman 2000; Teimoury et al. 2013), and it is computed as

$$\text{indicated retail markup} = \text{retail markup} \times \text{effect of retail inventory} \tag{11.43}$$

Effect of retail inventory is expressed as a non-linear graphical function of relative inventory coverage of the retail rice.

These equations were solved numerically using Runge–Kutta fourth-order method, and the solution interval dt was taken to be 0.25 which is less than half of the shortest first-order delay.

11.5 Model Validation

Initial values and the parameters were estimated from the primary and secondary data (BBS 2011; Bhuiyan 2014). The data on milling inventory, wholesale inventory and retail inventory used for simulation of supply chain of the rice milling systems in Bangladesh are shown in Table 11.1.

To build up confidence in the predictions of the model, various ways of validating a model such as checking the structure of the model, comparing the model predictions with historic data, checking whether the model generates plausible behaviour and checking the quality of the parameter values were considered. Time series data of wholesale prices of rice in Bangladesh in 2011 were compared with the simulated wholesale rice prices to build up confidence in the model, and

Table 11.1 Data used for the simulation of rice supply chain in Bangladesh

Item	Initial value, tones	Lead time, days	Demand average, tonnes	Ordering cost, taka[a]	Carry rate, fraction of product cost (1/year)
Milling inventory	2,500,000	7	950,000	500,000	0.15
Wholesale inventory	1,500,000	7	950,000	500,000	0.15
Retail inventory	2,500,00	7	95,000	50,000,000	0.15

Sources: BBS (2011) and Bhuiyan (2014)
[a]1 US dollar = 78.30 Bangladeshi taka

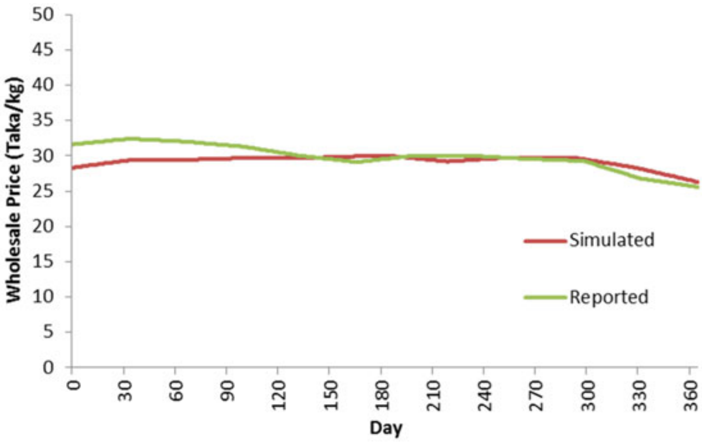

Fig. 11.3 Comparisons of the predicted and reported values of wholesale price in Bangladesh in 2011

this is shown in Fig. 11.3. The model-simulated prediction agrees reasonably well with historical behaviour. Also the model was tested for extreme conditions to detect the defect in the model structure and enhance the usefulness of the model for policy analysis. Figure 11.4 shows simulated milling inventory, wholesale inventory and retail inventory under extreme condition of crop failure, i.e. zero crop production. Under this condition, the milling inventory and then wholesale inventory and retail inventory are reduced to zero since the rice production is zero. The model results confirmed to the expected patterns of results and realities. This model complied with the basic principles of supply chain management and was consistent with supply chain theory and research results. The model is able to provide qualitative and quantitative understanding of the supply chain performances of rice milling systems. Hence, the model is reliable, and the validated model was used for policy analysis.

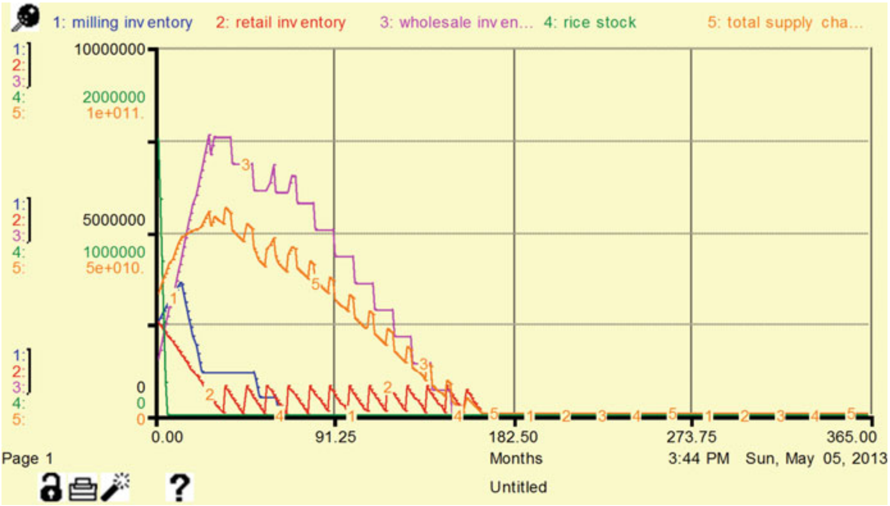

Fig. 11.4 Simulated rice stock, total supply chain cost, milling inventory, wholesale inventory and retail inventory under extreme condition of total crop failure

11.6 Simulation and Policy Analysis

Figure 11.5 shows the simulated milling inventory, wholesale inventory and retail inventory for economic order quantity and reordering point operation of the order rate of milling, wholesale and retail. Economic order quantity and reordering point operation of the order rate of milling, wholesale and retail of the supply chain of rice milling systems stabilises the retail inventory and retail supply of the rice for consumption is ensured. However, there is a bullwhip or Forrester effect due to economic order quantity and reordering point operation of the milling, wholesale and retailing. Four major causes of bullwhip effect are demand updating, order batching, price fluctuation and rationing and shortage gaming. In this study, mainly the demand updating and order batching in the form of economic order quantity and reordering point operation, respectively, caused this bullwhip effect. Ideally inventory level should be as low as possible, but increased inventory is justified to meet the increased demand if the cost is low, and stock-out means failure to meet consumer demand. The milling and wholesale inventories fluctuate due to seasonal supply of rice, and this causes the rice milling industries to starve for rice for milling during the off-season of rice production. The milling inventory reduces to zero during the off-season of rice production, while the wholesale inventory accumulates rice from the harvesting season and reaches the peak at early part of the year to maintain the supply to the retailer for sustainable availability of rice to the consumers during the off-season, and then it decreases until rice from new

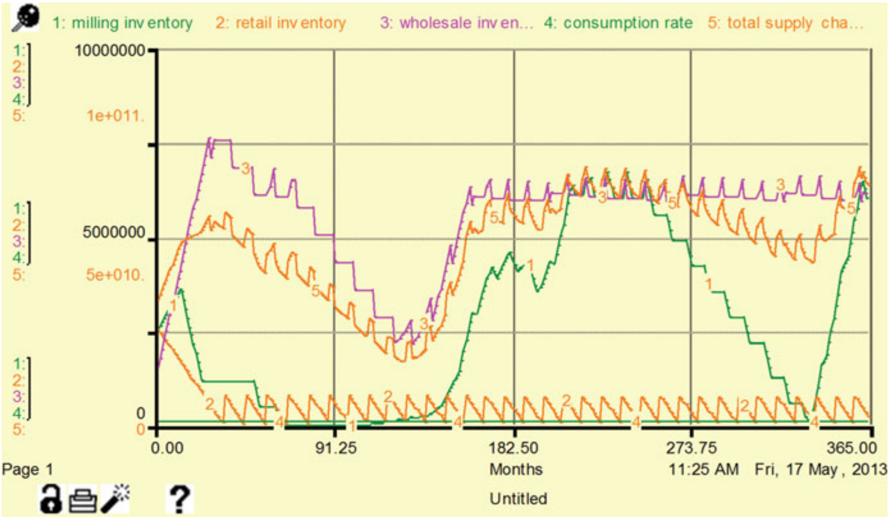

Fig. 11.5 Simulated milling, wholesale and retail inventory, daily rice requirement and total supply chain costs for economic order quantity and reordering point operation of the order rate of milling, wholesale and retailing

harvest is available. Then it increases and remains stable for rest of the period of the year.

To assess how the supply chain of the rice milling systems in Bangladesh would behave for any other ordering policies, the model was simulated for lead time average demand (demand average × lead time) policy. Although lead time average demand (demand average × lead time) order quantity and reordering point operation policy stabilises the retail inventory in a pattern similar to the economic order quantity policy, it increases the bullwhip effect and total supply chain cost. The annual total supply chain cost increases by 2.64 times the annual total supply chain cost of economic order quantity and reordering point operation of the milling, wholesale and retailing. This demonstrated the potentiality of using economic order quantity operation policy for supply chain management of rice milling systems.

The model was also simulated to address the impacts of rice productivity on the supply chain performances. Here the rice productivity is the yield of rice per ha. Rice productivity may be reduced from crop damage due to floods or pest infestation, and also it can be increased by development of higher yield hybrid rice through research and development. Rice productivity for this policy is defined as

$$\text{rice production rate} = \text{area under rice} \times \text{yield of rice} \tag{11.44}$$

$$\text{yield of rice} = 1.81, 2.81 \text{ and} 3.81 \text{ tons/ha} \tag{11.45}$$

Simulated milling inventory, wholesale inventory, retail inventory and total supply chain cost for rice productivity of 1.81 tons per ha, 2.81 tons per ha (present average rice productivity) and 3.81 tons per ha are shown in Figs. 11.6a, 11.6b, 11.6c and

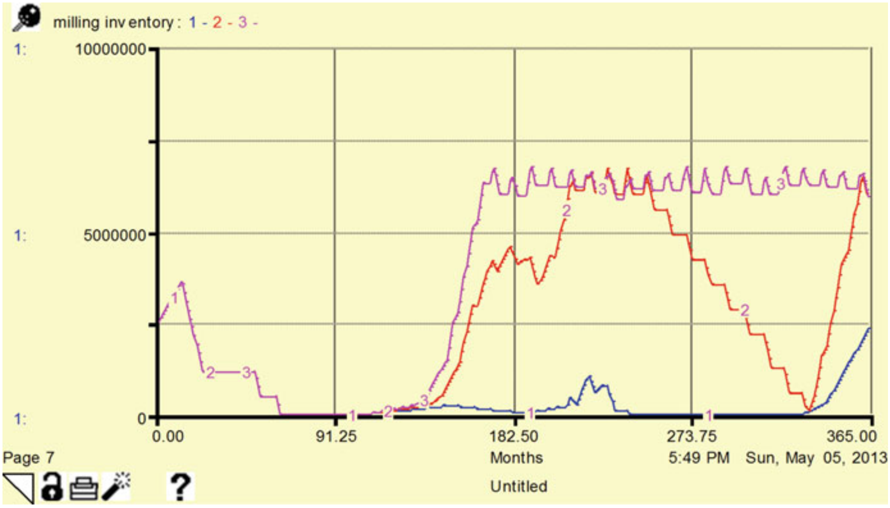

Fig. 11.6a Simulated milling inventory for rice productivity of 1.81 tons per ha, 2.81 tons per ha and 3.81 tons per ha

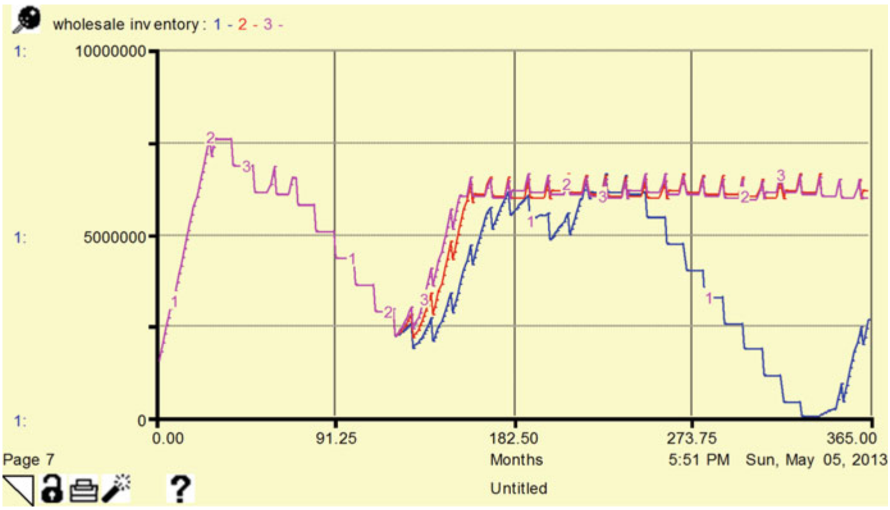

Fig. 11.6b Simulated wholesale inventory for rice productivity of 1.81 tons per ha, 2.81 tons per ha and 3.81 tons per ha

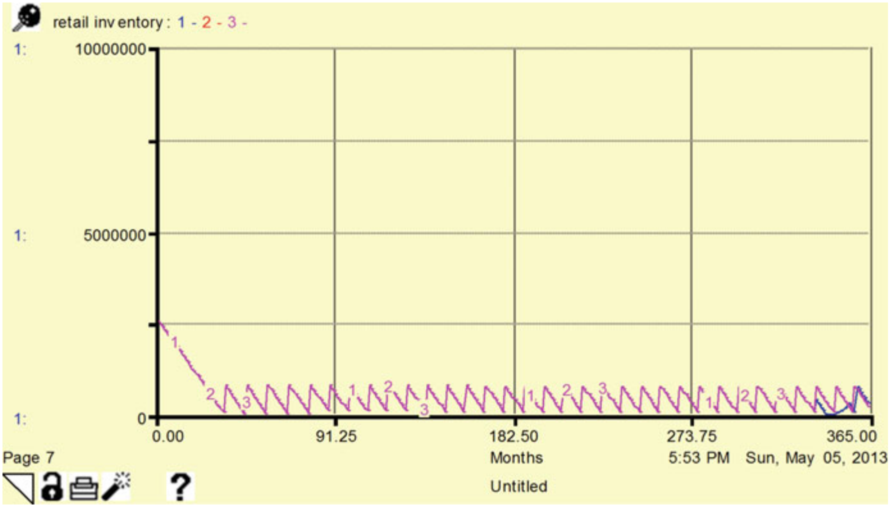

Fig. 11.6c Simulated retail inventory for rice productivity of 1.81 tons per ha, 2.81 tons per ha and 3.81 tons per ha

11.6d, respectively. Milling inventory is reduced to zero for most of the period of the reduced productivity of rice (1.81 tons per ha), while it is high for bumper production of rice (3.81 tons per ha) (Fig. 11.6a). Wholesale inventory is reduced significantly in the fourth quarter of the year for reduced rice productivity (1.81 tons per ha) (Fig. 11.6b). Total supply chain cost is also reduced in the third and fourth quarter of the year for reduced rice productivity (Fig. 11.6d). However, in all the cases, the retail inventory is almost the same except towards the end of the year when both milling and wholesale inventories are empty for reduced productivity (Fig. 11.6c). Thus, increased wholesale inventory is a possible solution for the retail inventory to face the shortage of rice during the off-peak harvesting season of rice production. This implies that as long as wholesale inventory is available, the retail inventory is stabilised based on economic order quantity and reordering point operation of milling, wholesale and retail inventory. This demonstrates that the policy based on economic order quality and reordering point can ensure the availability of rice even under reduced production of rice, i.e. during crop damage/failure unless both wholesale and milling inventories are empty.

The model was also simulated to assess the impacts of lead times on the supply chain performances. Lead time can be defined as the time it takes from when first a need for a product is determined until it arrives on the doorstep and the reordering point and safety stock depend the lead time. Reordering point and safety stock for milling, wholesale and retailing for this policy are defined as

$$\text{reordering point} = (\text{ demand aver} \times \text{lead time }) + \text{safety stock} \tag{11.46}$$

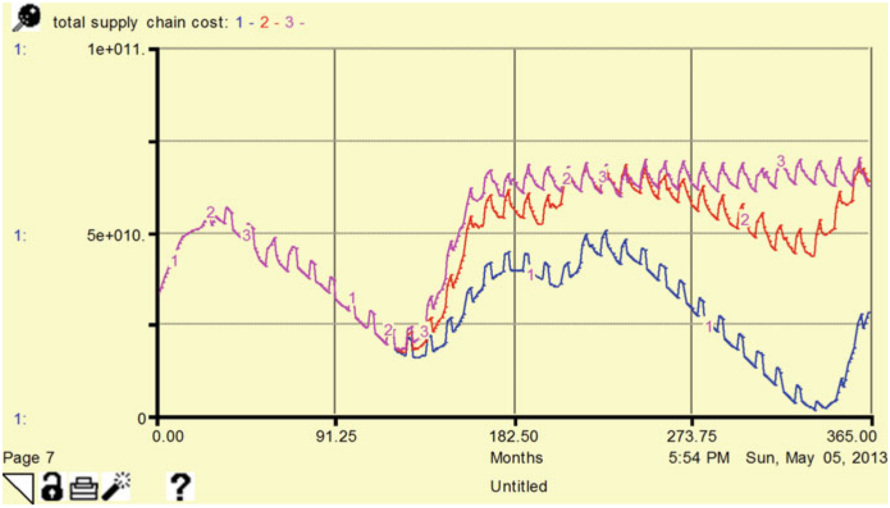

Fig. 11.6d Simulated total supply chain cost for rice productivity of 1.81 tons per ha, 2.81 tons per ha and 3.81 tons per ha

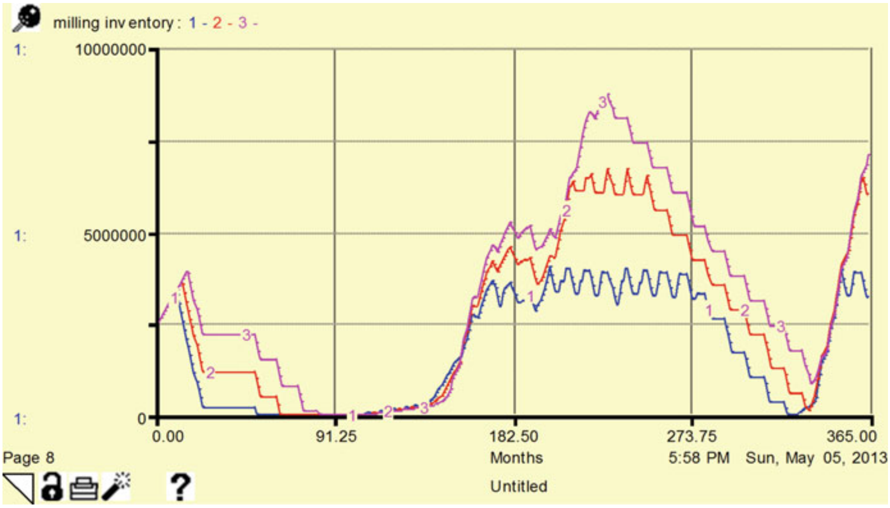

Fig. 11.7a Simulated milling inventory for milling lead time of 4 days, 7 days and 10 days

$$\text{safety stock} = \text{safety factor} \times \text{standard deviation of demand aver} \times \text{SQRT(lead time)} \tag{11.47}$$

$$\text{lead time} = 4,\ 7 \text{ and } 10 \text{ days} \tag{11.48}$$

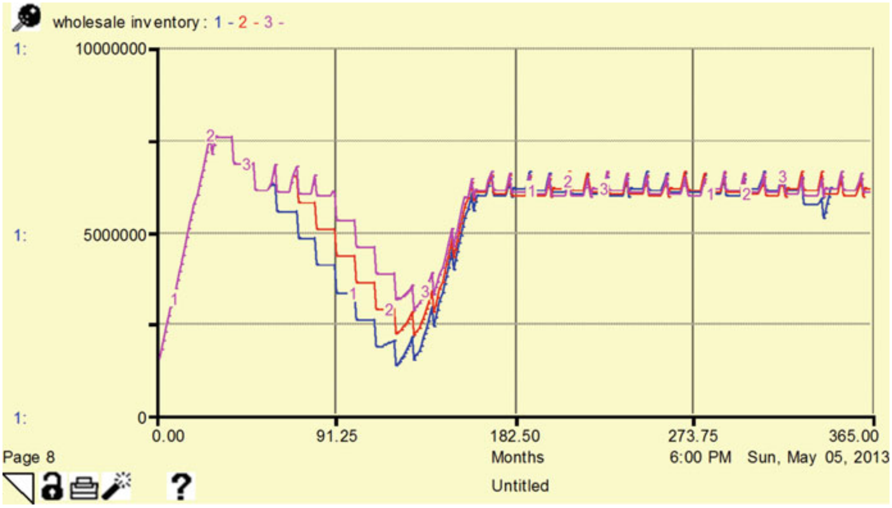

Fig. 11.7b Simulated wholesale inventory for milling lead time of 4 days, 7 days and 10 days

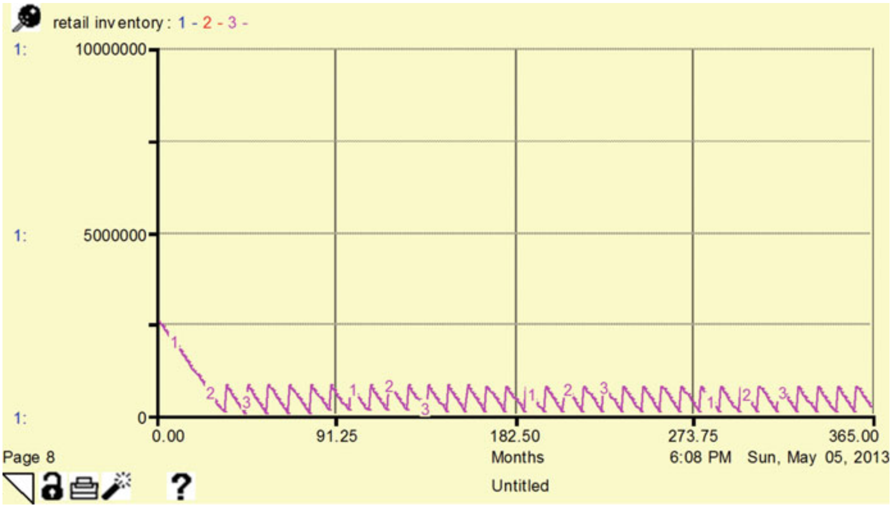

Fig. 11.7c Simulated retail inventory for milling lead time of 4 days, 7 days and 10 days

Simulated milling inventory, wholesale inventory, retail inventory and total supply chain cost for milling lead time (4, 7 and 10 days), wholesale lead time (4, 7 and 10 days) and retail lead time (4, 7 and 10 days) are shown in Figs. 11.7a, 11.7b, 11.7c, 11.7d, 11.8a, 11.8b, 11.8c, 11.8d, 11.9a, 11.9b, 11.9c and 11.9d, respectively.

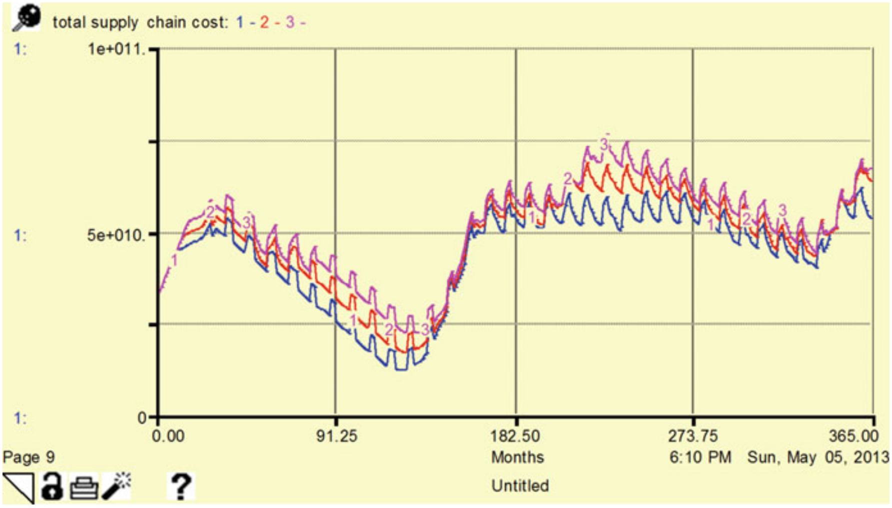

Fig. 11.7d Simulated total supply chain cost for milling lead time of 4 days, 7 days and 10 days

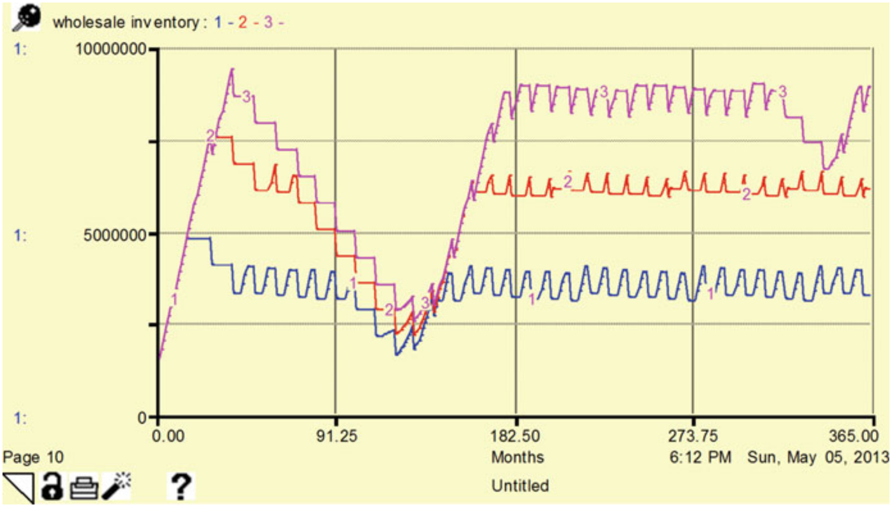

Fig. 11.8a Simulated wholesale inventory for wholesale lead time of 4 days, 7 days and 10 days

Firstly let us consider the impacts of milling lead time on supply chain performances for milling lead time of 4 days, 7 days and 10 days. Milling inventory increases considerably with the increase in the milling lead time (Fig. 11.7a). Wholesale inventory and total supply chain cost increase little with the increase of milling lead time (Figs. 11.7b and 11.7d), but the retail inventory remains almost

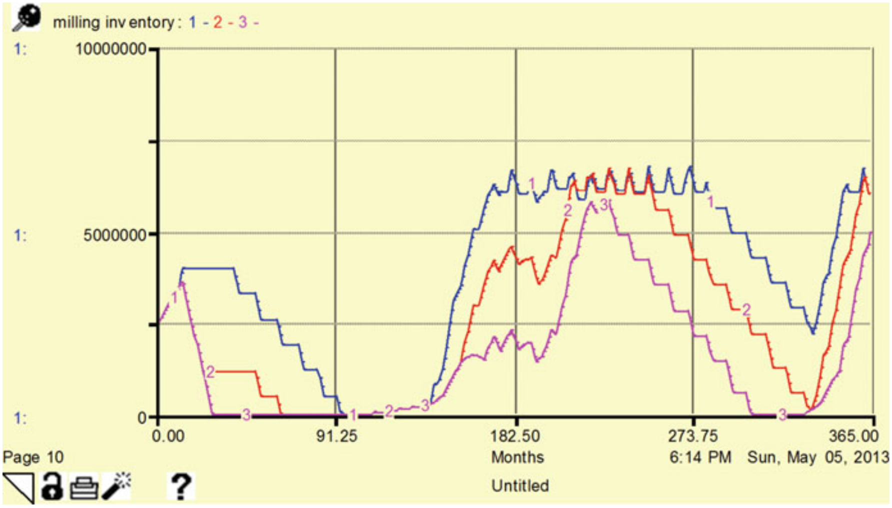

Fig. 11.8b Simulated milling inventory for wholesale lead time of 4 days, 7 days and 10 days

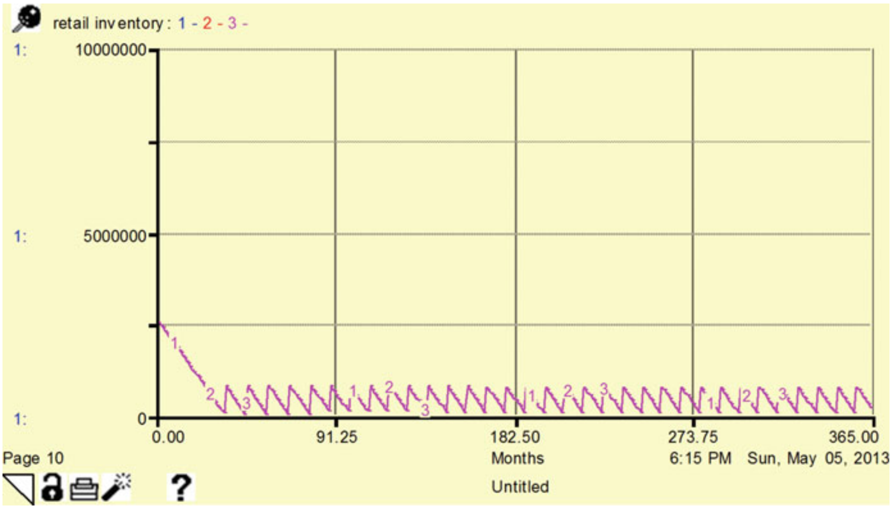

Fig. 11.8c Simulated retail inventory for wholesale lead time of 4 days, 7 days and 10 days

unchanged (Fig. 11.7c). In essence the major impact of the changes in milling lead time is reflected on the milling inventory, but the impact on the retail inventory is a minimum.

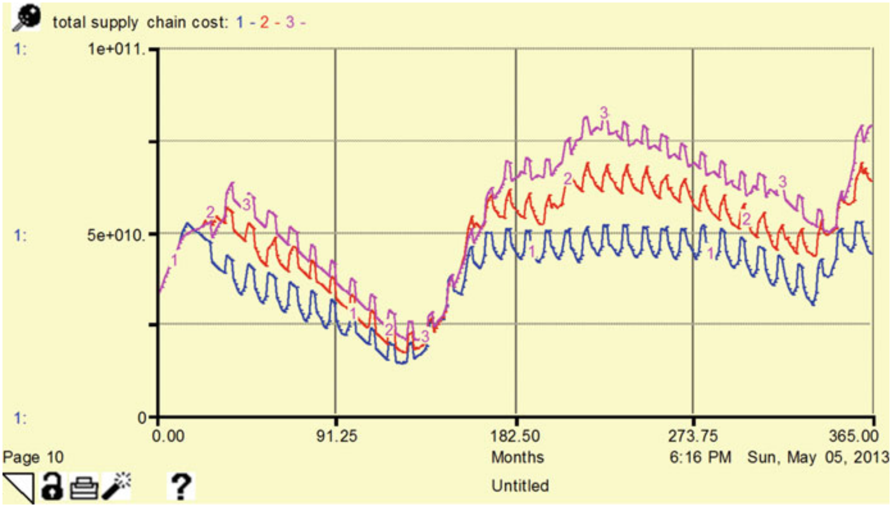

Fig. 11.8d Simulated total supply chain cost for wholesale lead time of 4 days, 7 days and 10 days

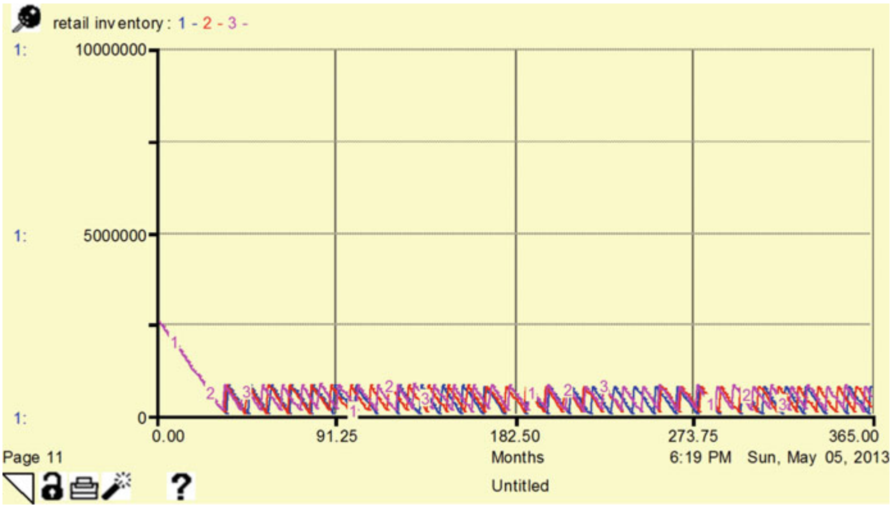

Fig. 11.9a Simulated retail inventory for retail lead time of 4 days, 7 days and 10 days

Secondly let us consider the impacts of wholesale lead time on supply chain performances for wholesale lead time of 4 days, 7 days and 10 days. Simulated wholesale inventory, milling inventory, retail inventory and total supply chain cost for wholesale lead time of 4 days, 7 days and 10 days are shown in Figs. 11.8a,

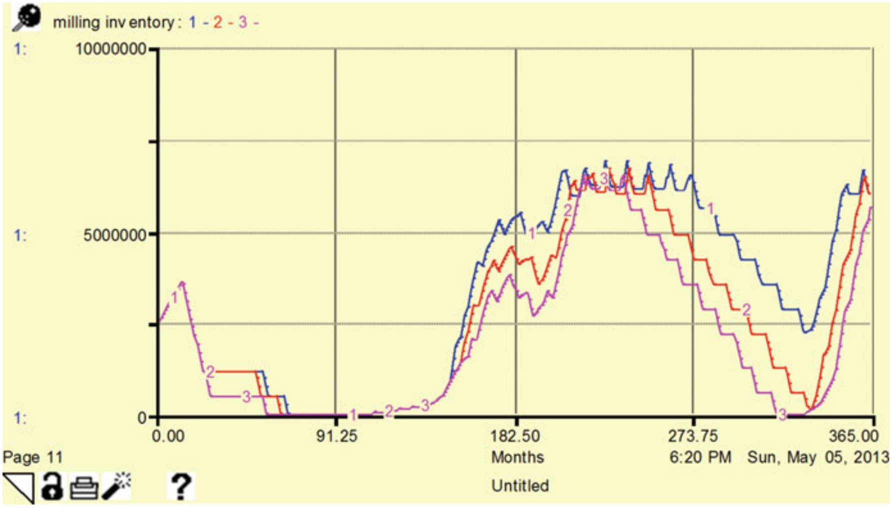

Fig. 11.9b Simulated milling inventory for retail lead time of 4 days, 7 days and 10 days

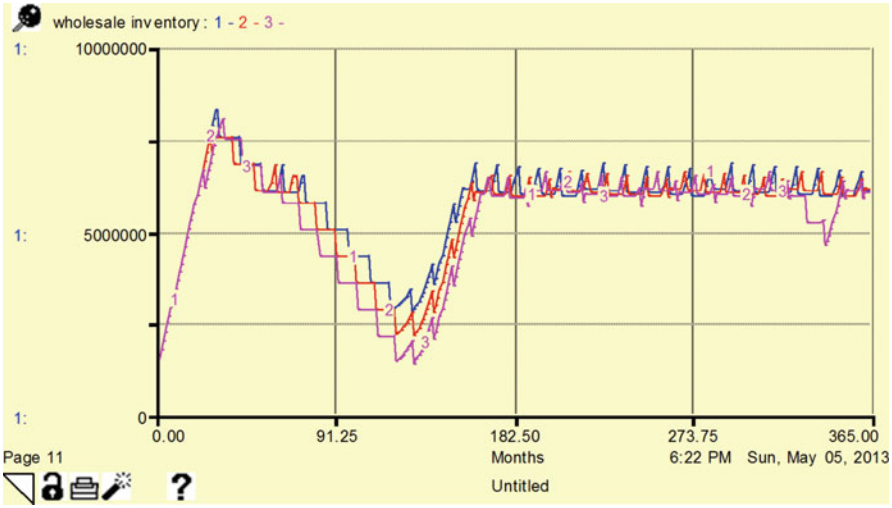

Fig. 11.9c Simulated wholesale inventory for retail lead time of 4 days, 7 days and 10 days

11.8b, 11.8c, and 11.8d, respectively. Wholesale inventory and total supply chain cost increase with the increase of wholesale lead time (Figs. 11.8a and 11.8d), while milling inventory decreases (Fig. 11.8b), and the changes are relatively large, but the retail inventory remains almost unchanged (Fig. 11.8c). In essence the major impacts of the changes in wholesale lead time are reflected not only on the changes

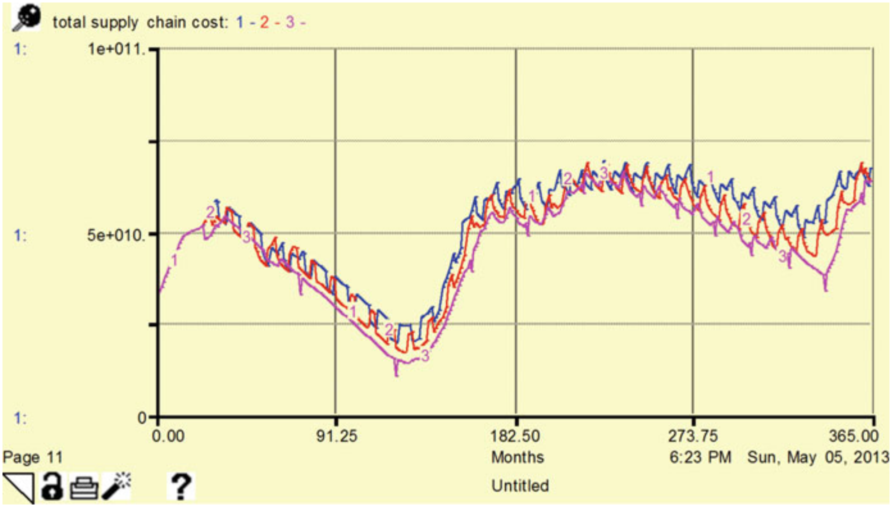

Fig. 11.9d Simulated total supply chain cost for retail lead time of 4 days, 7 days and 10 days

of wholesale inventory but also on the milling inventory and total supply chain costs. However, the impact on the retail inventory is a minimum.

Thirdly let us consider the impacts of retail lead time on supply chain performances for retail lead time of 4 days, 7 days and 10 days. Simulated retail inventory, milling inventory, wholesale inventory and total supply chain cost for retail lead time of 4 days, 7 days and 10 days are shown in Figs. 11.9a, 11.9b, 11.9c and 11.9d, respectively. Retail inventory increases very little with the increase of retail lead time (Fig. 11.9a). But the effects of lead time changes are more prominent in the second half of the simulated period, and the milling inventory decreases with the increase in retail lead time (Fig. 11.9b). The wholesale inventory and total supply chain cost show small changes for changes in retail lead time, but each category follows similar patterns with time within a narrow band (Figs. 11.9c and 11.9d).

It is demonstrated that the policy based on economic order quantity and reordering point can ensure the availability of rice even under changes in lead time and demand average in the supply chain of the rice milling systems. However, the bullwhip or Forrester effect remains present in the system. Forrester (1961) and Sterman (1989) ascribe behavioural causes to the bullwhip effect, where Lee et al. (1997a, b) suggest that the bullwhip effect also occurs due to operational causes. The lack of supply chain coordination results in bullwhip effect which distorts the demand information in the supply chain and increases the supply chain cost. The most obvious remedy to counter demand signal processing is collaboration, but it generally does not completely eliminate the problem (Moll 2013). The largest increase in total supply chain cost occurs for the increase in the wholesale

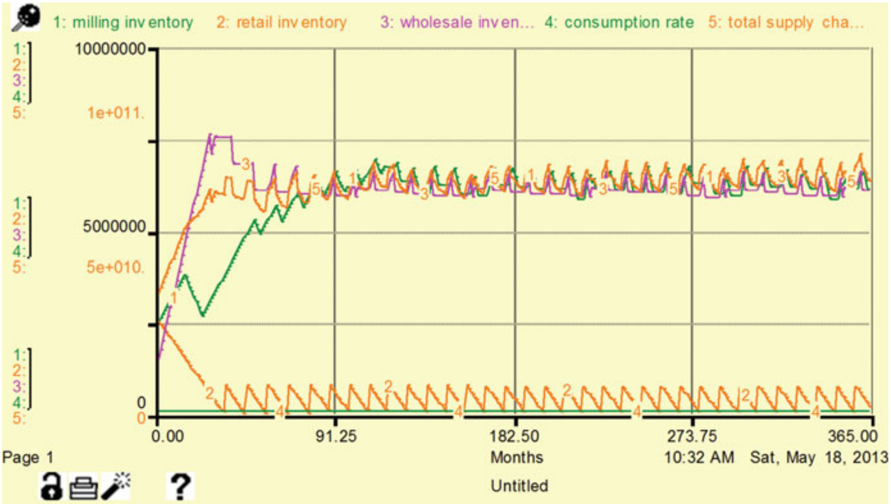

Fig. 11.10 The impacts of the round-the-year supply of rice to the milling industries on wholesale inventory, retail inventory and total supply chain costs

demand average, and this indicates that supply chain cost increases at the wholesale stage of the supply chain. In essence the major influence of the retail lead time and demand average is on the milling inventory.

The model was also simulated to assess the impacts of the round-the-year supply of rice to the milling industries on wholesale inventory, retail inventory and total supply chain costs. Round-the-year equal amount of supply of rice is ensured by the round-the-year equal amount of release of rice from the storage for sales for milling. The rice supply to milling industries is defined as

$$\begin{aligned} &\text{rice inventory } (t) = \text{ rice inventory } (t-1) \ + \text{rice supply rate} \times \Delta t \\ &-\text{rice sales for milling} \times \Delta t \end{aligned} \quad (11.49)$$

$$\text{rice suply rate} = 97955 \text{ tons/day} \quad (11.50)$$

Figure 11.10 shows the impacts of the round-the-year supply of rice to the milling industries on wholesale inventory and retail inventory. The simulated results show that round-the-year supply and the use of rice to the milling industries not only stabilise the milling inventory but also the whole system. This implies that if rice is dried initially for safe storage and then used round the year, the whole system can be stabilised. However, the bullwhip or Forrester effect remains present in the stabilised system.

The simulated results of the model demonstrate that the economic order quantity and reordering point for milling, wholesale and retail inventories not only ensure the availability of rice to the consumers during poor harvest (as long as stock is available from wholesale inventory) but also near optimal order quantities. Annual total supply chain cost for economic order quantity is 2.64 times less than the total supply chain cost for lead time demand average, and a major share of this cost is for transportation which requires fossil fuels. Hence economic operation results in less fuel consumption and hence less contribution to global warming.

Sustainability in three dimensions is widely accepted, and this allows easy comprehension of the integration of economic, environmental and social issues (Seuring 2013). Economic order quantity and sustainable supply of rice to consumers in this study address the economic and food security issues while less contribution to global warming addresses the environmental issue.

This study brings systems approach to understanding and managing the different activities needed to coordinate the rice milling systems to best serve the ultimate customer of rice in Bangladesh. With the proposed model planners and plant managers can visualise the milling, wholesale and retail inventories and the supply chain costs as well as even can be used to determine the storage facilities needed to ensure the availability of rice to the consumers. The actors in the rice supply chain make decisions individually and collectively such as milling and ordering activities. Some of these decisions influence the capabilities and effectiveness of the supply chain. Also Seuring and Müller (2008) emphasise the need of increasing cooperation along the supply chain, if sustainability goals are to be reached. Participatory system dynamics modelling uses system dynamics perspective in which stakeholders or clients participate to some degree in different stages of the modelling process, including problem definition, system description, identification of policy levers, model development and/or policy analysis. Participatory system dynamics/multi-agent system modelling of the rice milling supply chain involving all the stakeholders is recommended for future study. This model can be used for participatory modelling of rice milling systems. Overall, the proposed model can be used to study and analyse 'what if' scenarios of the supply chain of the rice milling systems.

11.7 Conclusion

A system dynamics model of supply chain of rice milling systems in Bangladesh is developed for policy analysis, and the retail inventory is fully stabilised for economic order quality and reordering point resulting in an efficient and sustainable supply chain network. Productivity reduction of seasonal production of rice causes changes in the milling inventory, wholesale inventory and total supply chain cost, but the retail inventory remains constant as long as the wholesale inventory is not empty. Lead time changes have positive influences on the directly related inventory level, and the changes are more pronounced in the milling and wholesale inventories. Also the influence of the demand average is dominant on the milling inventory. Round-the-year operation of the milling industries increases the stability of the whole system. Also the less total supply chain cost from economic operation results in less fuel consumption and hence less contribution to global warming. This model facilitates identification and study of the critical components of the overall supply chain, allowing for the creation of an efficient and sustainable supply chain network. This model also provides greater insight and better understanding of the supply chain of rice milling systems, and it can be used as a computer laboratory for developing scenarios for policy analysis

Exercises

Exercise 11.1 Why a computer model is a necessity to analyse and support rice milling systems. Discuss where to use operations research and system dynamics in supply chain management.

Exercise 11.2 Draw the causal loop diagram of the supply chain of rice milling systems. Draw another causal loop diagram for sustainable supply chain management.

Exercise 11.3 Draw stock–flow diagrams of both the causal loop diagrams in exercise 11.2 and compare the simulated results of retail inventory and retail price.

Exercise 11.4 Draw causal loop and stock–flow diagrams of supply chain of rice milling systems incorporating economic order quantity and reordering point for sustainable development. Simulate the retail inventory, retail price and contribution to global warming.

Exercise 11.5 Simulate both the models in exercise 11.2 to assess the impacts of round-the-year supply of rice to the milling industries and also assess the contribution to global warming.

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