Lateral Inventory Share based Business Model for IoT Enabled Sustainable Food Supply Chain Network

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Abstract

Recent Industry 4.0 developments have created disruptive changes and forces companies to rethink the way they design their supply chains. To cope with recent Industry 4.0 trends and changed requirements, supply chains need to become more connected, much faster, more granular, and much more precise. Digitisation of supply chain enables fast, flexible, granular, accurate, transparent, efficient, and sustainable transformations in supply chains. In this work, we study a business model for digitised food supply chain connected with their equivalents under an IoT environment. Specifically, we study a connected online grocery network design aiming to minimize food waste in the network and manage a sustainable food supply chain by considering a lateral inventory share-based food inventory management. Minimization of food waste is one of the recent significant concerns for sustainable food supply chain network designers. In an effort to contribute this target, we propose a lateral inventory share model for online groceries where one e-grocery can make a commercial transaction with another one. We study a single echelon network with three online groceries and simulate the proposed models to compare their performances.

Keywords
Lateral inventory share, inventory share, B2B, food supply chain network and food waste

1. Introduction

The effects of new digital technologies on Industry 4.0, the Information and Communication Technologies, the Internet of Things (IoT) developments, and cyber-physical system (CPS) architecture, have influenced production logistics and Supply Chain (SC) applications in terms of implementation and acceleration of innovations (Garay-Rondero et al. 2019; Tu et al. 2018). The influence of disruptive technologies such as digitalisation and Industry 4.0 leads to new way of modelling, implementations, principles in supply chain management (Ivanov et al. 2019). Therefore, these technologies allow new SC operating models that supplement or even substitute the traditional strategies (Hahn, 2020; van Alstyne et al. 2016). These rapid changes in the different markets and the economic, financial, social, and technological viewpoints imply that supply chains are in a state of continuous movement and development (Garay-Rondero et al. 2019). For that reason, companies must adapt to these rapid changes and rethink their supply chain design to capture the era. Within this scope, the integration of digital technologies into the supply chain gain importance in terms of meeting changing trends and understanding the barriers and challenges. Industry 4.0 brought some trends in the supply chain. Some of these trends are a continuous acceleration in rural areas across the world and services to regions that were not previously served because of globalization and increased population. Also, increasing and rapid changes in customer expectations with the effect of e-commerce and based on increased and personalized customer expectations brought much stronger granularization to the orders. Moreover, while the individualization and customization trends lead to increases in orders, it causes some changes and growth in the SKU portfolio. Also, customer expectations about delivery time decrease. To meet these current trends, digitalisation in supply chain needs is a must for companies to be faster, flexible, granular, accurate, transparent, efficient and sustainable. To manage these challenges, manufacturers and wholesalers typically increase the flexibility of their inventory systems by implementing a combination of emergency lateral transshipment (LT) from other depots at a higher cost, while at the same time backorder from their usual vendors to satisfy the stochastic demand (Lau et al. 2016). Especially, the inventory of the perishable products is an increasing concern in warehouses because the perishability of the food affects the quality of the product, price, and waste (Nakandala et al. 2017). Thus, the preservation of these fast perishable products is important to minimize food waste. Customers' demand for higher product diversity in perishable food products affects the supply and demand uncertainty for the market (He et al. 2014; Mahto and Kumar, 2008; Chen and Zhang, 2010). According to these changes in customer demand for fresh and perishable products, supermarkets adopt their retailing format, emphasizing the importance of the vegetable department as the center of their operations (Nakandala et al. 2017). However, the management of the perishable product is challenging for supermarkets and grocery retailers because these products are most likely to spoilage and damage that can cause financial loss via substantial lower the price near expiry of the shelf life of mere disposal (Nakandala et al. 2017).

This study aims to present a lateral inventory share based business model for digitised food companies that are able to share information under IoT environment to minimize food waste in their online groceries. For this purpose, three different online groceries at the same echelon level are considered. Then, a B2B model based on lateral inventory share policy is simulated to compare how food waste amount is affected based on its alternative when there is no inventory share. Section 2 presents literature review, Section 3 explains the problem definition along with its simulation details. Section 4 analyzes the results and provides comments on the results.

2. Literature Review

There are numerous studies that focus on lateral transhipment. The latest study by Yan et al. (2019) used a case study and developed a two-echelon and multi-location continuous inventory review model including time constraints. The objective was to reduce overall costs, respectively minimizing the waiting time while inspired by the penalty mechanism on order delivery. In addition to the stockouts, lateral transshipments and emergency transfers proceed to help balance supply and demand. Wijk et al. (2019) analyzed a two stock-point inventory model that allows for lateral transshipment of components among stock-points following the entry of demand for advanced technological structures. Results revealed that the optimal lateral transshipment policy was a policy of threshold kind and appropriate circumstances in which a (zero) hold back policy or a complete policy of pooling was ideal. Li et al. (2019) explored a compromise across the advantages and disadvantages of retailers ' lateral transshipment behavior and offers realistic perspectives into the lateral transshipment stock control issue. Therefore, Avci (2019) performed a simulation-based optimization of a retail network of numerous distribution centers and numerous retailers. She examined the impact of lateral transshipment and accelerated shipments on supply chain efficiency in the case of disturbances. Zhi and Keskin (2018) researched a multi-product, three-stage network with direct and lateral transshipments to determine the highest effective network configuration to reduce the overall fixed facilities and transport costs. Two solution algorithms centered on simulated heuristics of the annealing and GRASP were suggested. The results of the experiment demonstrate that the simulated annealing and GRASP algorithms exceed the best heuristic in the literature depending on dispersing search for both the quality and length of the alternative, specifically for large-scale problem contexts of stricter capacity. Rabbani et al. (2018) suggested a heuristic, theoretical-based graph algorithm to address a multi-echelon responsive supply chain channel design with lateral transshipments. At retailers, recognition of lateral transshipment offers a trade-off between shipping costs and inventory handling costs. The findings show that the suggested algorithm produces answers of good quality in a short period relative to the same solver. Yan and Liu (2018) used the system dynamics approach to construct an inventory transshipment model focused on multi-echelon supply chains, including suppliers, distributors, and retailers. Analyses revealed that the average stock level has moderately adjusted and deteriorated from the single- to four-chain product transshipment models. With growing transshipment costs, the narrowing spectrum of the average consumer satisfaction rating continually lowers. Nakandala et al. (2017)

suggested a lateral transshipment design that integrates distortion cost in the total inventory cost with the other factors, which are transactions by a standard manufacturer, lateral transshipment, backorder, and storage, and helps improve the trade-off between these main cost factors. Results demonstrate that in the higher distortion cost scenario lesser lateral transshipment costs are expected to activate the decision stage for enforcing lateral transshipment. Nonetheless, lateral transshipment is always the chosen approach to reduce overall inventory costs, despite the rules of decision being followed. Firouz et al. (2016) discovered the problem of multi-sourcing, supplier selection and inventory for a company's lateral transshipments selling a single product across several warehouses. Contrary to current literature, experimental findings suggest that inferior decisions will lead when evaluating the collection of suppliers exclusively for unit and/or contract costs. To direct professional resource management, Lau et al. (2016) suggested five lateral transshipment decision principles with a case-based guideline. Findings indicate superior success in inventory management with the introduction of a combined reactive and proactive lateral transshipment approach.

Paterson et al. (2011) classified lateral transshipment into two categories: proactive and reactive transshipment. Proactive transshipment takes place at predetermined times, to prevent backorder. In reactive transshipment, lateral transshipment takes place as a response to stock outs or potential stock outs if there is sufficient stock in another stocking point at the same echelon. In this study, we consider reactive transshipment type of inventory share specifically for online orders. Namely, instead of a physical transhipment, the shared inventory is sent to the ordering customer directly different from a transhipment case.

Tlili et al. (2012) suggested an inventory system focused on three parts: the inventory management model, the trans-shipment policy and the rationing policies. Findings demonstrate that the transshipment advantages tend to rise as the standard deviation rises, along with the lead time for the supplier and/or the lead time for the manufacturer goes higher. Findings also indicate that transshipment in view of the standard deviation is useful in an uneven inventory model. The empirical study additionally indicates that the rationing policy method does not substantially impact process output in the sense of maximum demand fulfilment. Tiacci and Saetta (2011) analyzed the relative effectiveness of two lateral shipment strategies in which the mean supply delay with regards to a traditional non-lateral shipment strategy by performing a two-echelon supply channel simulation experiment. Analysis revealed substantial decreases in the mean supply delay once lateral shipments are permitted in virtually any network arrangement with regard to the classical approach.

Ben-Daya et al. (2019) conducted a literature review of Internet of things and supply chain management. Results suggest that most research with restricted analytical models and observational experiments have concentrated on comprehending the effects of IoT. However, several research have concentrated on the supply chain structure and the supply chains for food and manufacturing. Bonilla et al. (2018) carried out a literature-based study to address the effect of Industry 4.0 on sustainability and its obstacles. Findings demonstrate that it can truly improve environmental sustainability only by the incorporation of Industry 4.0 with the environmental sustainability targets. Cederlöf (2016) examined the geographical ramifications of low-carbon urban farming in Cuba by pursuing the regional perspective emerging from studies on low-carbon energy transfer and agro-ecological and magnitude of growth.

There are few studies considering more than a single item type in the reactive lateral transshipment literature. Wong et al. (2005) considered multi-item, single-echelon and continuous timing of ordering with reactive lateral transhipment where inventory control policy was (S-1, S).

Different from the literature, in this paper, we consider an s, S inventory control implementation as well as an online marketing case for perishable products under a reactive lateral inventory share policy. Ekren and Arslan (2019) studied s, S inventory control model to compare the different lateral transshipment policies in a single-echelon network. However, in that model they study single item to minimize cost. They conclude that lateral transhipment work better than no lateral transhipment policy. Ekren and Ornek (2015a, 2005b) studied s, S inventory control problem by using simulation based optimization.

Few number of studies consider perishable products such as food in lateral inventory share literature. Dehghani and Abbasi (2018) proposed a lateral transshipment policy for perishable items (blood) considering age of the oldest item and reduced the total inventory cost. Berk and Gürler (2008) developed an analytical model that considers (Q, r) control policy for perishable products and provided significant cost saving. Once again, different from literature, we study an online grocery case in which physical transhipment does not take place and instead the shared inventory is directly sent to the online customer's pickup address.

3. Problem Definition

3.1 System Description

In this study, a single-echelon food supply chain network with three online groceries that are served by a main depot is considered. Figure 1 shows the studied network's design. Demands arrive at the online groceries randomly for three types of food products (i.e., perishable food products) having different product lives. Food products that are not sold until their expiration dates become *food waste* and they are thrown away. Remember that this work aims to study how inventory share affects (i.e., diminish) food waste in an online grocery network. Here, online grocery refers to the purchase of fresh and packaged food through online portals. With the recent information technology developments, as in increased trend in e-commerce, online grocery is also growing rapidly from its small base. In the Online Grocery Report (2019), it is declared that the online grocery market value has doubled from 2016 to 2018. This result supports that consumers are starting to get more comfortable ordering essentials and certain foods online. Hence, it is expected that online grocery market would keep growing more in the following years. Therefore, it would worth to work business models (i.e., inventory share policies) for online groceries to find out good policy designs decreasing food waste while increasing the profitability of the network.

The studied online grocery network is assumed to be connected under an IoT environment where each online grocery can share its inventory information as well as demand information with another one (see Figure 1). In an effort to reduce food waste, arriving demand is met by an online grocery having the closest expiration date. In the study, our aim is to find out the optimal *s*, *S* inventory levels for each product type under the proposed inventory share policy in that connected network. Besides, we also aim to understand how the performance (i.e., total food waste amount) of the system is affected when there is inventory share compared to when there is no inventory share . We simulate the proposed system scenarios whose assumptions are summarized in the below subsection.

We study an *s*, *S* inventory control policy. Namely, when the inventory level of any food product type in any grocery falls to below of its reorder level *s*, an order quantity of *S* – inventory level is placed to replenish the inventory for up-to level *S*.

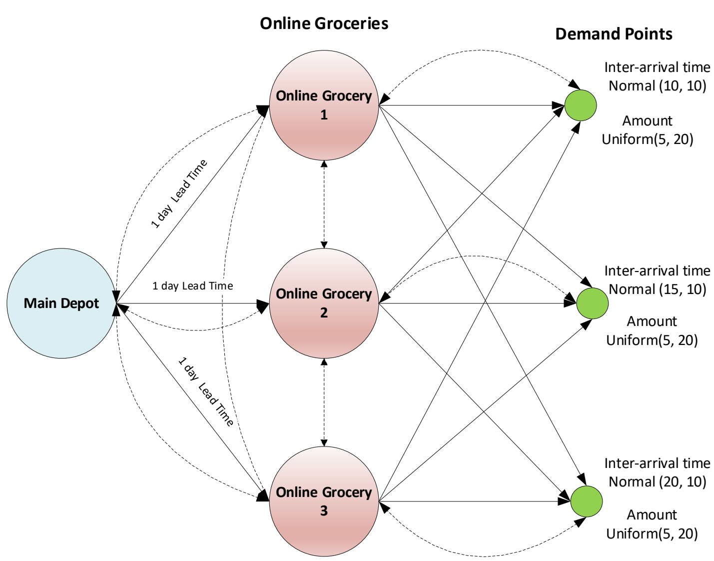

Figure 1. Single-echelon online grocery network

3.2 Simulation Model and Assumptions

Simulation modelling approach is utilized to test how the pre-defined business models (i.e., inventory share versus not inventory share policies) affect the performance of the studied online grocery network. The systems are modelled by using the Arena 16.0 commercial software. The appropriate *s, S* levels are optimized by the *OptQuest* optimization tool provided in this software.

The simulation model assumptions are summarized as follows:

- There are three online groceries at the same echelon (Figure 1).
- Mean inter-arrival times for demand follow normal distribution with Normal (10, 10), Normal (15, 10) and, Normal (20, 10) hours for online grocery 1, online grocery 2, online grocery 3, respectively.
- The probability distribution for each type of product is discrete and has the same probability with 1/3. Namely, an arriving demand is assigned to a product type with 1/3 probability.
- There are three product types, P1, P2, P3, in each grocery whose shelf lives are assumed to be: 3, 7, 10 days respectively.
- Mean amount of demand for a product type arriving at a grocery follows normal distribution with Uniform (5, 20) products.
- In the inventory share policy, demand is met by the grocery having the closest expiration date.
- The inventory review policy is continuous and *s*, *S* policy.
- The online grocery food product requirements are filled up by a main depot with infinite capacity.
- Lead time from the main depot is one day for each online grocery.
- If the entire amount of demand cannot be met by the groceries, the whole is considered as lost sale. The customer service level (CSL) is calculated by (1) accordingly.
- It is aimed to obtain at least 95% CSL in the optimization procedure.
- The simulation is run for one year with one month warm-up period.
- Ten independent replications are performed.

The CSL is calculated by (1) and the notations used in the study are provided below:

$$CSL = 1 - LS / TD \tag{1}$$

LS : total amount of lost sale during the simulation run
TD : total amount of demand in the network during the simulation run
CSL : customer service level (calculated by (1))
LT : total amount of lateral inventory share in the network during the simulation run
sST : total amount of replenishments in the network during the simulation run
I_{ij} : inventory level of product i, at online grocery j at the observed time
I_i : total inventory level of product i in the whole network at the observed time
s_{ij} : re-order level for product type i, at online grocery j, $i = \{1, 2, 3\}$, $j = \{1, 2, 3\}$
S_{ij} : up-to level for product type i, at online grocery j, $i = \{1, 2, 3\}$, $j = \{1, 2, 3\}$
D_{ij} : demand amount for product type i, arriving at online grocery j, at a time $i = \{1, 2, 3\}$, $j = \{1, 2, 3\}$
Q_i : total amount of product type i spoiled (i.e., food waste) in the network during the simulation run
O_{ij} : order amount of product i ordered from the main depot for online grocery j at a time

In order to evaluate the proposed lateral inventory share policy, we also simulate a system without inventory share policy. In that case, demand is always met by its online grocery. Again, if there is not enough amount of demand at that grocery, the whole demand is assumed to be lost sale. Figure 2 shows the simulation flow chart for the model with lateral inventory share policy. Figure 3 shows the flowchart for the alternative model, with no inventory share policy. In addition to those figures, the flowchart for the continuous *s, S* review policy is illustrated in Figure 4.

To be able to compare the two policies, we observe the total amount of food waste happened at the network (i.e., $\sum Q_i$), LT, and sST.

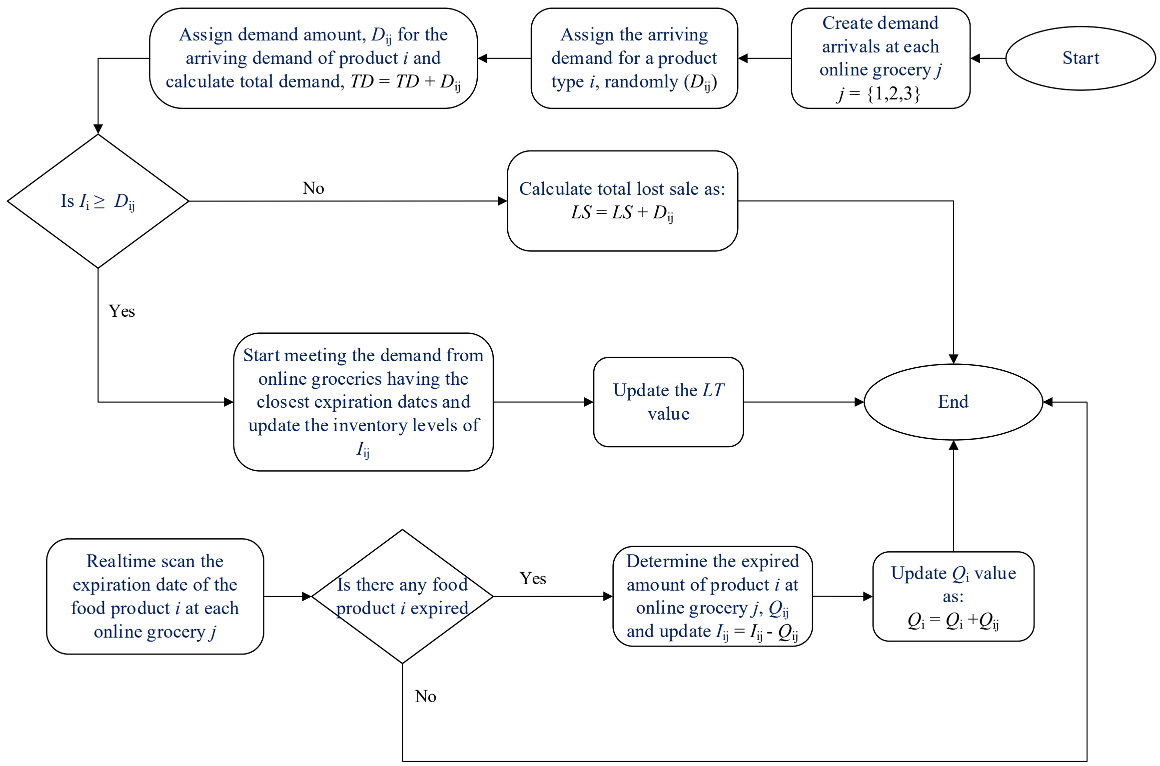

Figure 2. Flowchart of the simulation model with lateral inventory share policy

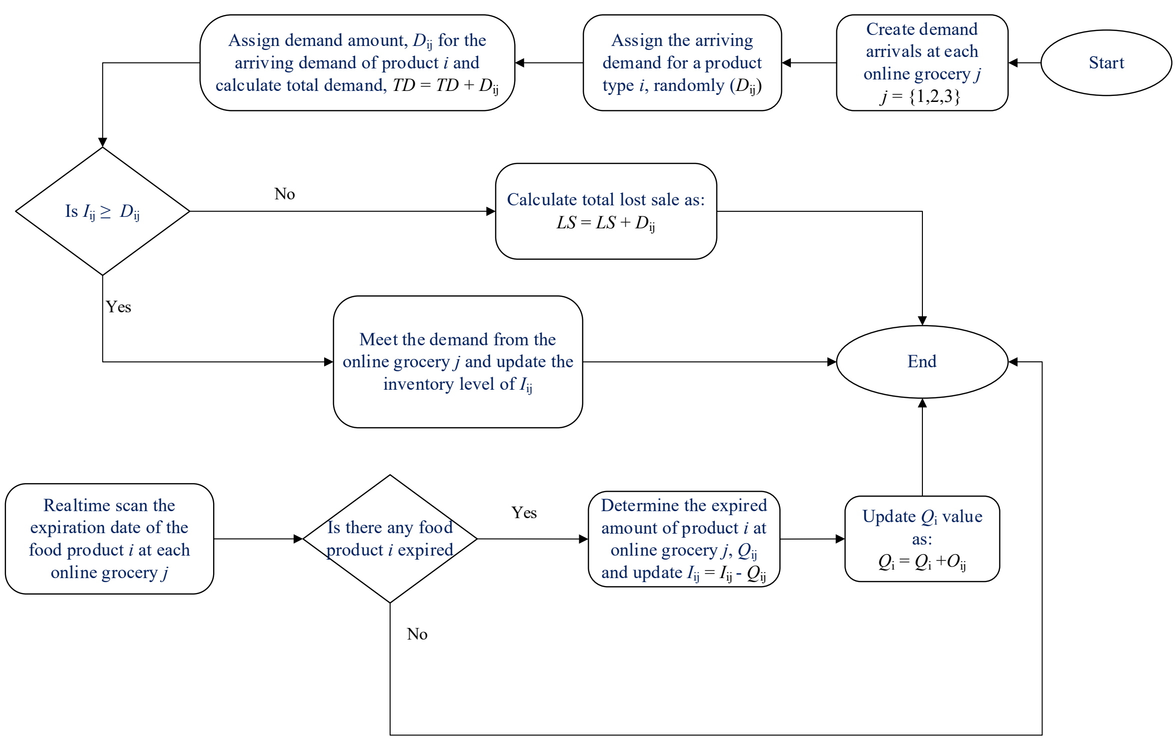

Figure 3. Flowchart of the simulation model with no inventory share policy

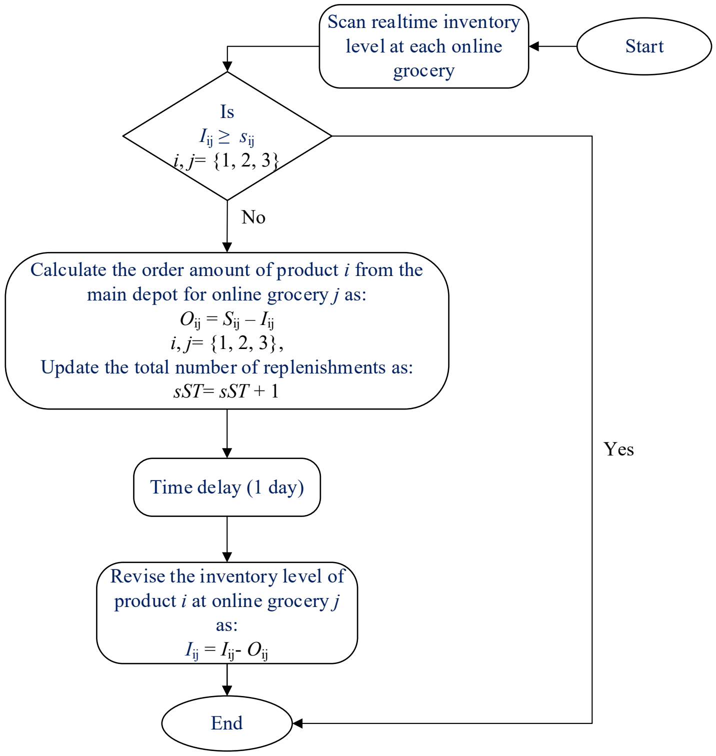

Figure 4. Flowchart of continuous inventory control in simulated model.

3.3 Simulation Optimization to Determine the *s, S* Levels

In order to find out the optimal levels for the *s*, *S* levels of each product type in online groceries, we use an optimizer tool provided by the Arena 16.0 software. This optimization tool is developed on heuristic algorithms. The tool combines several meta-heuristics approaches such as tabu search, neural networks, and scatter search (Kleijnen and Wan 2007). It allows us to define linear constraints for the simulation optimization. Here, we define CSL to be larger that 95% and calculated by (1). First, the user specifies the lower, suggested, and the upper values for the decision variables (i.e., *s*, *S* levels) to be optimized.

Once again, the decision variables in the optimization are the *s, S* levels of each product type in each online grocery. Hence, we have 3 × 3 × 2 = 18 decision variables to optimize. The objective function is considered to be the minimization of total food waste amount in the network shown by (2).

$$\text{Min} \sum_{i}^{3} Q_i \tag{2}$$

4. Results and Comments

Figure 5 shows a screen shot from the OptQuest result for the scenario with lateral inventory share. According to that figure, the optimal level is contained at the point of 1,488 total food waste amount. All the results are summarized in Table 1 and 2.

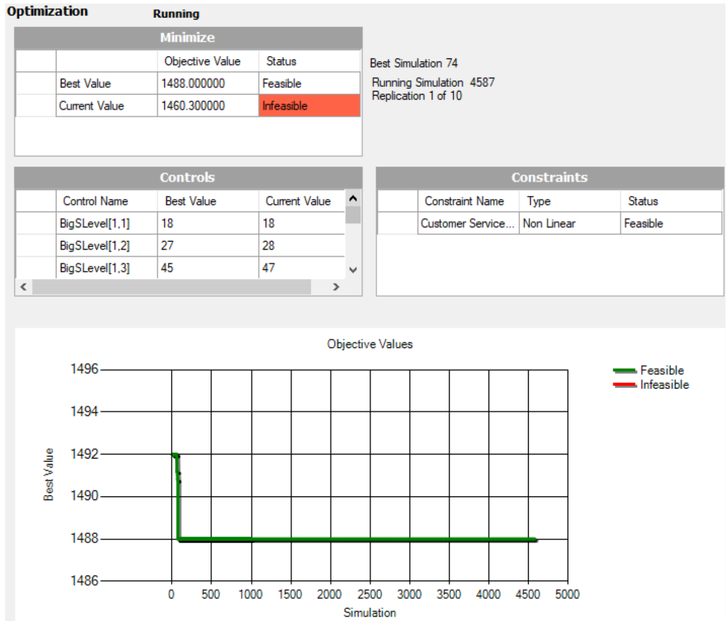

Figure 5. A snapshot from *OptQuest* screen for policy of lateral inventory sharing

Table 1 shows the optimal results of *s*, *S* levels for each product type based on online groceries in the network. According to that table, it is observed that the *s*, *S* levels are typically larger in the no inventory share policy than the lateral inventory share policy. Table 2 shows the performance outputs from the optimal results. When we see Table 2, it is observed that total food waste is pretty much when there is no lateral inventory share in the network. The replenishment number is also larger in that policy compared to that lateral share policy

Table 1. Optimal *s, S* inventory levels obtained by *OptQuest*

Online Grocery (*j*)	*s*, *S* levels for policy with lateral inventory share			*s*, *S* levels for policy with no inventory share		
	(s_{1j}, S_{1j})	(s_{2j}, S_{2j})	(s_{3j}, S_{3j})	(s_{1j}, S_{1j})	(s_{2j}, S_{2j})	(s_{3j}, S_{3j})
1	(16, 18)	(9, 27)	(12, 45)	(50, 51)	(33, 45)	(33, 57)
2	(15, 19)	(10, 24)	(10, 29)	(40, 42)	(41,44)	(40,47)
3	(15, 20)	(6, 34)	(16, 31)	(45, 46)	(40, 41)	(34, 35)

Table 2. Some performance metrics obtained at the optimal levels of *s*, *S* for each scenario

Policy	$\sum Q_i$	*LT*	*sST*	*CSL*
Policy with lateral inventory share	1,488	1126	1396	95,02%
Policy with no inventory share	9,828	0	2030	95,31%

5. Conclusion

In this paper, a lateral inventory share based business design model is proposed to provide a sustainable food supply chain network for online groceries. With today's technological developments it is possible to have a connected supply chain network under IoT environment to manage the whole network efficiently. We explore whether or not a network benefits under inventory share policy. We consider a single echelon online network design for food marketing. We optimize the *s*, *S* levels under two business models, inventory share and no inventory share policies, and compare their performances mainly in terms of total amount of food waste in the network. The results show that inventory share policy makes enormous amount of improvement in food waste minimization and worth to consider as a future business models in food supply network. As a future work, it would worth to explore more business models by also including cost related data in the evaluation procedure.

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