Managing your supply chain pantry: Food waste mitigation through inventory control

Xun Wang[a,*], Vasco Sanchez Rodriguez[a], Emrah Demir[a]

[a] Logistics and Operations Management Section, Cardiff Business School, Cardiff, UK, CF10 3EU
* Corresponding author.

Abstract

In this paper, we report through case study findings that the food supply chain can be improved by implementing a proper inventory control policy. The case study involves an online retailer who sells predominantly food products. The improvement of the case company is shown via simulation in economic, social and environmental aspects. The findings indicate the role of supply chain risk as an obstacle in achieving supply chain sustainability, and the benefit of effective inventory control as a cost-advantageous and easy-to-implement waste reduction method.

Introduction

In a perfect world without waste, all waste produced can ultimately find its destination and contribute to the system (Timko, 2019). However, when it comes to food waste, huge barriers exist in terms of geography, technology and management. This is why food waste is becoming a global issue. It greatly impacts the three pillars of sustainability - economic, social, and environmental aspects of our world. According to UN FAO (2013), about 1.3 billion tons of food is wasted every year. This amount equals a direct economic loss of $936 billion. This translates to a carbon footprint 3.3 gigatons of emissions. The blue (fresh) water footprint of is about 250 cubic kilometres or 66 trillion gallons of water; or all the water in Lake Ontario in the Great Lakes.

Food waste also leads to a decrease in social welfare; social income, food security, health and well-being are each influenced. A full costing analysis shows that the total cost of food waste approximates to 2.6 trillion US dollars. This amount is roughly equal to the GDP of France (FAO, 2014).

Each stage of the food supply chain generates food waste. These stages include production, post-harvesting, processing, distribution and consumption. Globally, the production and retailing stage contributes to a majority of food waste (FAO, 2011).

Along the supply chain farmers and retailers have to cope with various uncertainties in their planning. Uncertainties include weather conditions, pests and diseases, consumer demand and retail orders. So they "sometimes make … plans on the safe side, and end-up producing [or procuring] larger quantities than needed, even if conditions are 'average' " (FAO, 2011).

In this paper, we report findings on food waste management from a case study with an online food retailer; a core member of a food supply chain. We particularly focus on consideration of one aspect of supply chain management, in only this stage, food inventory management, especially fresh food. That is, food waste can be mitigated through improved inventory control.

Case Company Food Waste Disposition

A large percentage of food retailer products include fresh, short shelf life food. The life of this food is typically only a few days in a warehouse, after which they have to be disposed, if not sold. The case study retailer has made a commitment to consumers on the freshness of food deliveries. Hence, any food disposal usually occurs before the actual expiration date.

The case company has adopted various measures to mitigate the negative impact of disposal for food waste. Some food that is not suitable for consumer sale and consumption is resold to staff at a discount. Food waste may be donated to food charities and zoos or used for anaerobic digestion to help mitigate disposal costs.

No matter the mitigation measure taken, there is still a direct economic loss. Social and environmental consequences also occur. For instance, it is difficult to control donated food quality, especially food about to expire. Thus, it is not always clear if all donated food is consumed. Emissions and water usage will also increase during these mitigation efforts either through additional food management or transportation activities.

The case company has defined a new term, 'purge', to refer to all products not sold to customers. This includes the food flowing to either the staff shop, charity donation, or disposal to a landfill.

Operations and Inventory Management in Food Waste Control

The operations management team of the case company was asked to determine what possibilities existed for the organization to manage food waste. Their understanding of food waste causes was shared with the research team. The case study research team conducted several interviews with the operations managers.

Managers pointed difficulty in forecasting consumer demand as a main cause of food waste cause. This task became more challenging than some other external uncertainties such as sudden weather changes. Additionally, it was found that short product shelf life further exacerbated the food waste problem.

Overall, we and the operations managers reached a conclusion that the root cause of food waste was poor and inefficient inventory control. Most food waste arises from excessive hence expired products. Inaccurate demand forecast and short shelf life only added to the difficulty of inventory control.

A data and simulation analysis was completed to show that a more cost-effective solution might be to re-examine their inventory control policy.

An inventory control policy is very much attuned with the organizational ordering policy. The ordering policy dictates decisions on order quantity using available forecast and inventory information. Using this information, future inventory levels can be controlled. A well-designed ordering policy is able to improve and balance inventory-related operational performance.

A number of important performance measures, and key performance indicators are used for this inventory and order policy management. They include:

- *Availability*. The number of days that inventory can meet demand, versus the total number of days within the scope of the planning period. The availability is of utmost importance to retail operations. It measures the percentage of consumers satisfied by the retail service.

- *Purge rate*. The number of purged products versus the total sales. The term 'purge' is interchangeable with food waste in the retailing scenario.

- *Average inventory level*. The average amount of inventory held daily, across all days within the time plan. Low inventory level indicates less opportunity cost from inventory investment. In the case of chilled food, low inventory also means fewer CO_2-equivalent emissions.

- *Inventory amplification*. The coefficient of variation (c.v.) of inventory versus the c.v. of sales. With low inventory amplification, the case study company is able to maintain an availability level with less inventory.

- *Order amplification*. The coefficient of variation (c.v.) of orders versus the c.v. of sales. The order amplification is an externality of retail operations based on supplier quantities. Reducing the order amplification leads to less risk faced by the supplier. This result in turn helps to improve supply chain sustainability by lessening food waste.

Digging into the Inventory Management Process Variables

Currently, the online food retailer makes daily food orders to its suppliers. The ordering policy in use is of the order-up-to type. The order quantity equals to the demand forecast plus safety stock less current inventory level. It was found that the accuracy of both the forecast and the inventory level information are satisfactory. The major discrepancy exists between the practice of setting safety stock.

The safety stock is a buffer amount as a risk precaution for demand and supply uncertainty (Arrow, 1958). We found that farmers tend to overproduce, thus supply uncertainty does not have a significant effect. Hence, safety stock exists as a buffer primarily for demand uncertainty, represented by the forecast error.

Demand uncertainty should not be confused with demand variability. To understand this, consider an imaginary case with a 100% accurate forecast, i.e. forecast error is zero. In this case, the safety stock can be set to zero. The ordering quantity equals the net demand -- demand minus current inventory level -- of the next day, irrespective of demand variability.

Inventory theory suggests that the safety stock should be a multiple of the standard deviation of the forecast error. The standard deviation measures the degree of the uncertainty. A multiplier reflects the desired availability. For example, more safety stock is needed for 99% availability than for 90% availability of product to meet demand. It is also common in practice to set the safety stock as a multiple of demand level. For example a policy of: “the safety stock is set as three days of sales”. This method is less accurate but easily understood by personnel. The managers must still establish a relationship between forecast error and demand level.

The online retailer set their safety stock using a different approach than what is purported by theory. They use a multiple of the standard deviation of forecast error multiplied to the forecasted demand.

There are two potential difficulties with this method. First, the safety stock and the order quantity are always greater than the theoretical recommendation. Thus, the inventory level is consistently higher than an optimal service level determination. Second, a fluctuation in forecast becomes the fluctuation of inventory and order quantity. The first phenomenon has an aggravating effect on the second outcome.

The managers have speculated that the following phenomenon is occurring due to their practice. In the first few days of the week, orders inflate as they follow their policy. The stock quickly builds up. A manual intervention, to fix any issues, occurs later in the week by lessening the order quantity. Overall, there is an over-sensitivity and overreaction of the order quantities and inventory level to the changes in sales.

Hence, paradoxically the worst of all worlds occurs; there is a high purge rate, high inventory level and a low availability situation. **Figure 1** replicates this phenomenon on the order quantity and inventory of one fresh product over a 90-day period. From the plots we see the described effects. We adjust the scales for comparison, but hide the actual numbers to maintain data anonymity.

Simulation shows the benefits of an improved ordering policy. In particular, setting safety stock at the theory recommended levels, mitigates this effect. The improved policy reduces amplification in the order quantity and inventory level. This leads to a lower purge rate and higher availability, see **Figure 1b and 1c**.

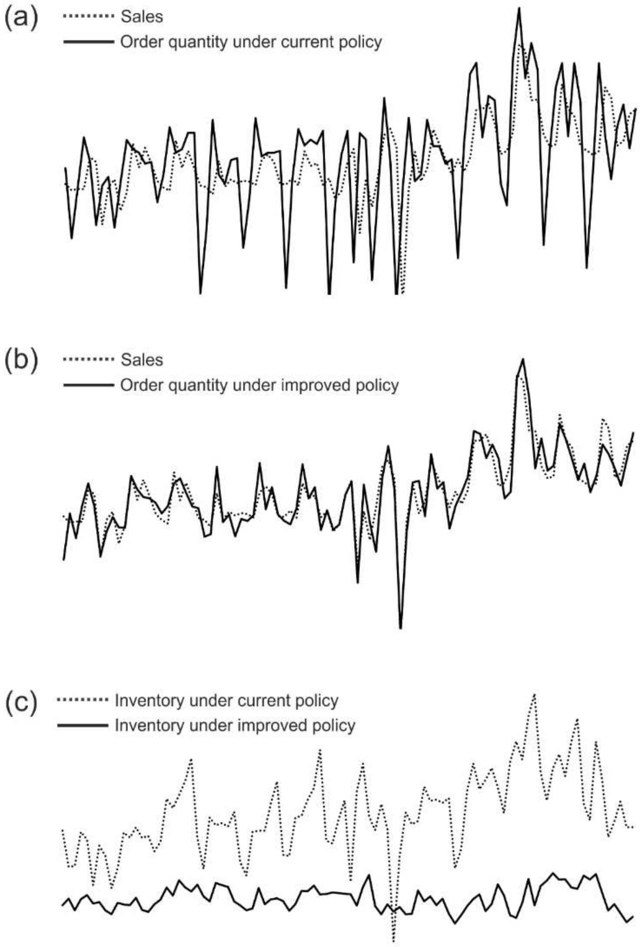

Figure 1 - Simulation of online retailer Inventory and Waste. **(a)** Sales and order quantity under the current ordering policy. **(b)** Sales and order quantity under the improved ordering policy. **(c)** Change in inventory level under the current and improved ordering policy.

We have also conducted a simulation on a wider range of fresh products with shelf life shorter than five days. We evaluated the performance of the policies by the average over these products; see **Table 1**.

By adopting the improved policy, the inventory fluctuation reduced by 48%. Thus, there is an improvement in both the availability (increased by 2%) and purge rate (reduced by 40%). The average inventory level also drops by 43%. Meanwhile, the order fluctuation also shows a mild reduction of 3.6%. This means that the retailer can benefit without adding operational difficulty to the suppliers.

Table 1 – Simulation results of a wider product range

	Current policy	Improved policy
Availability	0.977	0.999
Purge rate	4.955	2.970
Avg. inventory level *	1.000	0.573
Inventory amplification	1.135	0.589
Order amplification	1.136	1.095

* Standardized.

Some Lessons for Inventory Policy Adoption

This case study helped us to learn several lessons from the study.

First, it is clear that uncertainty and risk play a significant role in food waste generation. We can restrain the negative impact of demand uncertainty by applying proper ordering policies. The endless pursuit to improve forecasting accuracy is no longer necessary. In fact, a forecasting algorithm and ordering policy are important components of an inventory system. To maintain high availability and low waste, both must be designed properly. Updating an ordering policy, rather than focusing on forecasting improvements, is also economically friendly. This shift in focus saves on developing complicated forecasting algorithms, which may require significant information technology, model development, and management investments.

Second, these order policy improvements also improve social and environmental conditions of supply chain operations. With the reduction of purge and food waste, emissions and use of resources will drop. The retailer is able to adopt a more active and predictive strategy for food donation. Charities can receive fresh products with longer shelf life that can potentially be planned. This case study is an example that metrics on the three aspects of sustainability can be improved altogether, which helps to build a broader business case (Presley and Meade, 2018).

To achieve the above goal and insight for management, information on these metrics need to be available to various supply chain stakeholders, which require attempts in putting this information into existing decision support systems for green supply chain management (Govindan et al.; Sun and Zhu, 2018), as it can greatly benefit inventory and operations management of the food supply chain.

Third, it is important to build consensus among supply chain stakeholders on these metrics and policies. One example is in inventory and order amplification. For the retailer, the major goal is to reduce the inventory amplification. Meanwhile, there might be an order amplification resulting in demand uncertainty faced by the supplier. If a supplier expects a reduction in the amplification of the order quantity a conflict arises. Conflicts will emerge when the two metrics (inventory and order amplification) move in opposite directions (Disney et al., 2004). An agreed metrics system can help build support for implementation of ordering policies.

Last, from the perspective of collaboration, food supply chains can innovate in inter-organizational capabilities for win-win opportunities (Melander, 2018). The retailer can provide several initiatives to reduce the supply chain food waste. The retailer can share consumer demand information with the supplier. Demand information sharing is effective in reducing the supplier's demand uncertainty. As production-stage food waste usually surpasses retail food waste, such sharing initiatives can be beneficial.

However, supply chains must establish an incentive for the retailer to share such information, before successful implementation. This again requires consensus of benefit allocation among supply chain participants. In the case of the case company, a strategic policy is to be a “green” on-line food supplier. Thus, the incentive is to continue to manage its strategic policy and provide legitimacy to its vision.

Conclusion

Overall, we provide one example of how operations management theory and principles can improve food waste management in the supply chain. We only focus on a modelling and information sharing approach for one important relationship and linkage in the food supply chain. Other aspects include improving food waste sustainability in production through less usage of chemicals and resources, effective by-product development, and improved food technology storage and delivery.

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Dr Xun Wang is an Associate Professor of Operations Management and Management Science at Cardiff Business School. He received his PhD from Beihang University, China. Prior to this post he held a position of Lecturer in Logistics Management at Beijing Jiaotong University, China. Currently his research interest is on modelling and analysis of complex dynamics in inventory and supply chain management. His research articles have been published in various academic journals, including Journal of Operations Management, European Journal of Production Research and Omega.

Dr Vasco Sanchez Rodrigues is an Associate Professor in Logistics and Operations Management at Cardiff University. His research is innovative and cutting-edged and focuses on challenging areas such as carbon reduction, food waste prevention and mitigation, collaboration and supply chain risk management. Vasco is an industry-led academic who has undertaken successful applied-research projects for leading companies from the retail, food and drinks, and logistics sectors from the UK, South Africa and South Korea. Furthermore, he has published his research in internationally recognised academic journals such as International Journal of Operations and Production Management, Transport Research Part A, Part D and Part E and Supply Chain Management – An International Journal. Vasco is leading three externally funded research projects that together have £1.2 million of external funding. Prior to join UK academia, Vasco spent six years in BIMBO Organisation, a leading bakery multinational, holding a range of supply chain-based senior management roles.

Dr Emrah Demir is an Associate Professor in the Logistics and Operations Management Section of the Cardiff Business School. Before joining Cardiff University, Dr Demir worked as Assistant Professor at the Eindhoven University of Technology (Netherlands). He holds BSc and MSc degrees in Industrial Engineering from Baskent University (Turkey), and a PhD in Management Science from University of Southampton. Dr Demir's main research interest is positioned within the field of green logistics with respect to negative externalities of freight transportation. He has experience in teaching Logistics and Transportation, Operations Management, Project Management and Operational Research.