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Policy Decisions of Inventory Systems for Perishable Product under Shortages

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ABSTRACT: Past research on inventory management of perishables introduced models in which demand is sensitive to the age of the product. For such models, we prove that a fixed-order quantity policy is optimal under certain conditions and show that its expected cost is closer to optimal than that of the base-stock level policy when there is demand for units of all ages. We also know numerically when substituting older products to fulfill the demand for new (or vice versa) is beneficial. Perishable products require accurate inventory control models as their effect on operations management can be critical. This assumption is particularly relevant in highly uncertain and dynamic markets, as for the ones generated by the pandemic era. This article presents an inventory control model for perishable items with a demand rate variable over time, and dependent on the inventory rate. The article also considers the potential for backlogging and lost sales. Imperfect product quality is included, and deterioration is modelled as a time-dependent variable. The framework envisages the possibility to define variables affected by uncertainty in terms of probability distribution functions, which are then jointly managed via a Monte Carlo simulation. This article is intended to provide an analytical formulation to deal with uncertainty and time-dependent inventory functions to be used for a variety of perishable products. The formulation is designed to support decision-making for the identification of the optimal order quantity. A numerical example exemplifies the outcomes of the paper and provides a cost-based sensitivity analysis to understand the role of main parameters.

KEYWORDS: policy, inventory, perishable, shortages, products, decisions

I. INTRODUCTION

Inventories occur in all forms and for the most diverse purposes. We usually think of inventories as goods for sales, raw materials for production, work in progress held for later production stages, finished goods for supporting activities and customer service. But livestock in a farm, cash in a bank account, water in reservoirs, blood in blood banks, and personnel who need special training all have similar characteristics. They are all held to meet some future demands. They are all controllable within limits.[1,2] For many organizations inventories are a major investment. Inventory management is an important function in many organizations even in the Internet age. The fundamental questions in inventory control are when to order and how much to order. This article presents the complete survey of published literature in mathematical modeling of deteriorating items and shortages. A way to reduce waste in the food supply chain is to control the inventory levels in the supply chain. Inventory control has to deal with balancing conflicting goals, like on one hand the wish to produce in large batches to make use of economies of scale and on the other hand to lower the inventory levels to save on the capital tied up in inventory . In case of perishable products, inventory control also has to balance between product-availability and waste. [1,2]

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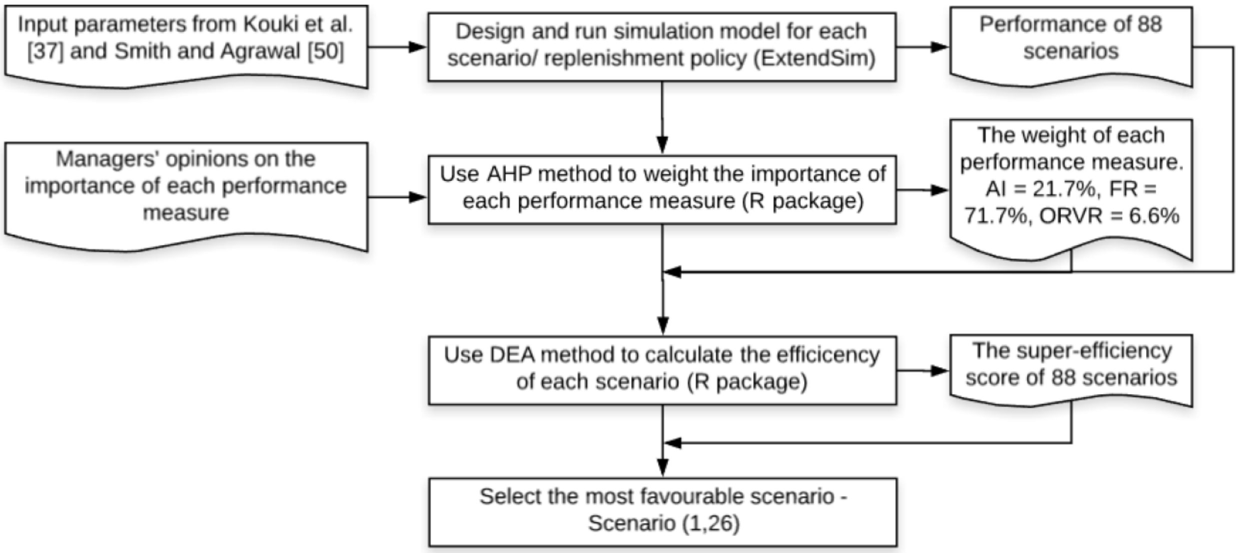

This review studies inventory control for a perishable product at several actors in the food supply chain. Therefore first a sketch of a food supply chain of a perishable product is given. Next the impact of perishability in the supply chain is briefly discussed, including issuing of product and common demand characteristics. The supply chain of a perishable food product starts with producing the raw material at a farm. Partly the raw material (mainly fruits and vegetables) finds its way unprocessed to the consumer, in a simple package, via wholesale trade or the auction.[3,4] Partly the raw material (e.g. milk, meat, fruits and vegetables) is transported to a food company where production takes place. The paper shows a simplified food supply chain containing the stages farm, food producer, warehouse and supermarket. In practice, the farm stage can contain several subsequent farms from breeder to fattener of animals, or from seed producer to vegetable grower. Food production can be production of raw milk into consumer packaged milk; production of cheese; production from slaughtering to a packaged meat product; washing, cutting and packing under modified atmosphere of fresh vegetables, etc. Production steps may be executed at several subsequent production companies or locations. After production, the final products are transported to a warehouse. This might be the location of a wholesaler or a logistics service provider, possibly followed by a retail distribution centre. [5,6]

II. OBSERVATIONS

Ordering, holding, and shortage costs make up the three main categories of inventory-related costs. These groupings broadly separate the many different inventory costs that exist, and below we will identify and describe some examples of the different types of cost in each category.[7,8]

Ordering costs, also known as setup costs, are essentially costs incurred every time you place an order from your supplier. Examples include:

- Clerical costs of preparing purchase orders — there are many kinds of clerical costs, such as invoice processing, accounting, and communication costs
- Cost of finding suppliers and expediting orders — costs spent on these will likely be inconsistent, but they are important expenses for the business
- Transportation costs — the costs of moving the goods to the warehouse or store. These costs are highly variable across different industries and items
- Receiving costs — these include costs of unloading goods at the warehouse and inspecting them to make sure they are the correct items and free of defects[9,10]
- Cost of electronic data interchange (EDI) — These are systems used by large businesses and especially retailers, which allow ordering process costs to be significantly reduced. There will be an ordering cost of some amount, no matter how small your order might be. The more orders

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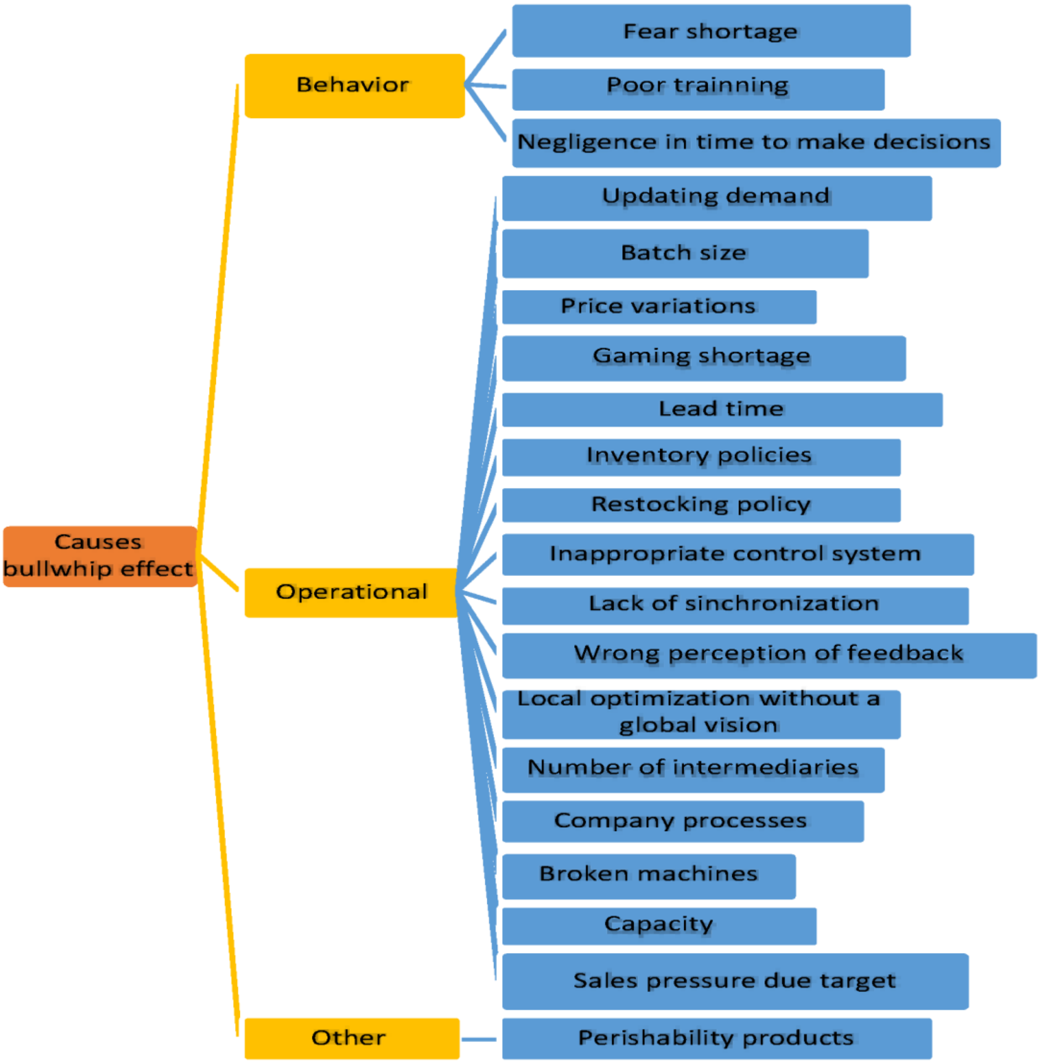
placed, the greater the ordering costs. This ordering cost can be spread out if you placed a bulk order to use goods over a long period of time. However, if your business orders raw materials only as needed so that it keeps little stock on hand, you might be able to tolerate high ordering costs as this is balanced by an overall lower holding cost[11,12]



Holding costs

Also known as carrying costs, these are costs involved with storing inventory before it is sold.

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- Inventory financing costs — this includes everything related to the investment made in inventory, including costs like interest on working capital. Financing costs can be complex depending on the business
- Opportunity cost of the money invested in inventory — this is found by factoring in the lost alternatives of tying money up in inventory, such as investing in term deposits or mutual funds
- Storage space costs — these are costs related to the place where the inventory is stored and will vary by location. There will be the cost of the storage facility itself, or lease payments if it is not owned. Then there are facility maintenance costs like lighting, heating, and ventilation. Depreciation and property taxes are also included in this
- Inventory services costs — this includes the cost of the physical handling of the goods, as well as insurance, security, and IT hardware, and applications if these are used. Expenses related to inventory control and cycle counting are further examples[13,14]
- Inventory risk costs — a major cost is shrinkage, which is the loss of products between purchasing from the supplier and final sale due to any number of reasons: theft, vendor fraud, shipping errors, damage in transit or storage. The other main example is dead stock

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Shortage costs

These costs, also called stock-out costs, occur when businesses become out of stock for whatever reason.

- Disrupted production — when the business involves producing goods as well as selling them, a shortage will mean the business will have to pay for things like idle workers and factory overhead, even when nothing is being produced
- Emergency shipments — for retailers, stock-outs could mean paying extra to get a shipment on time, or changing suppliers[15,16]
- Customer loyalty and reputation — aside from the loss of business from customers who go elsewhere to make purchases, the company takes a hit to customer loyalty and reputation when their customers are unhappy

Spoilage costs

Perishable inventory stock can rot or spoil if not sold in time, so controlling inventory to prevent spoilage is essential. Perishability is a concern for many industries such as the food and beverage, pharmaceutical, healthcare and cosmetic industries, all of which are affected by the expiration and use-by dates of their products. Spoilage not only costs money but also means you fail to realise a return on your initial investment.[17]

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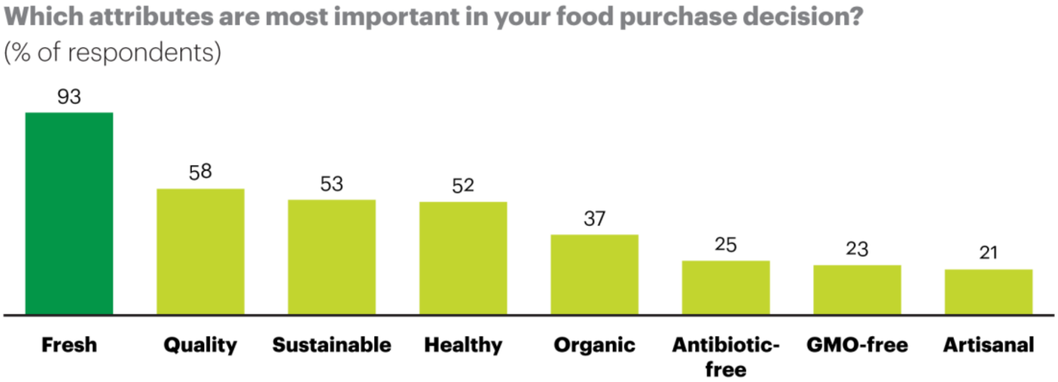
Figure 1

Consumers are turning to harder-to-source fresh foods



Source: A.T. Kearney analysis

Inventory spoilage and waste is not simply a result of isolated cases of poor inventory control, spoilage is now a global environmental concern. When you consider that in the United States alone, an estimated $200 billion is spent growing, processing, transporting and disposing of food that is never eaten.Solid inventory control is your front line to preventing spoilage and waste. With the right inventory system, you can improve forecasting, boost efficiency, access real-time inventory data and up-to-date information on the lifecycle of your stock, enabling staff to rotate and manage stock to ensure older products get sold first.[18,19]

This approach is used in the grocery and FMCG sectors where products with shorter expiry dates are rotated to the front of the shelf. Items that are due to expire are often heavily discounted to clear the inventory stock.

III. DISCUSSION

Perishable inventory management is similar to BWE research for two reasons. First, the information required in the supply chain (e.g., demand), is vulnerable to influence from external factors (e.g., disasters), and create demand fluctuations and BWE. Second, inventory policy is important for perishable inventory and is one of three research streams on BWE .Therefore, we contend that improved performance measurement can be developed by reviewing literature on the BWE and applying this to perishable inventory models. In review papers on BWE, the use of a single financial measurement is criticised as it only supports cost minimisation rather than continuous improvement of the organisation as a whole . It was insisted on multidimensional analysis of the BWE. Even if only considering a single firm, stated that a performance metric should be exact, non-financial, actionable, simple, and in forms of ratios that allow for testing, reviewing, revising, and involving organisational learning; even within a single-echelon many managers within the echelon have different metrics against which their work is judged.[20,21]

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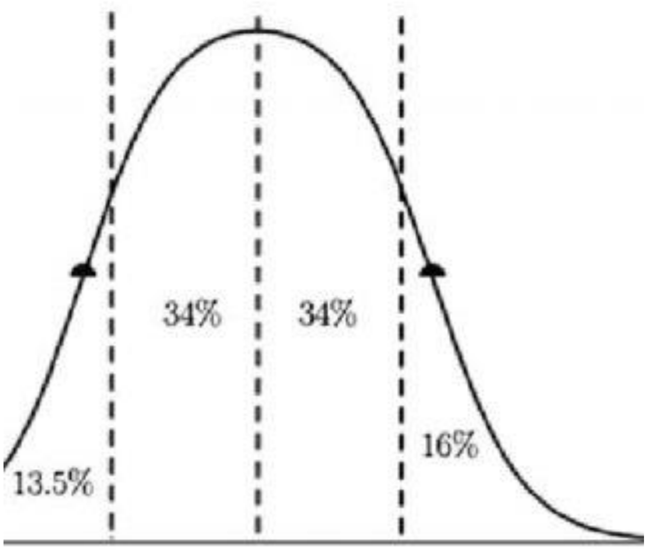

Inventory management of perishable products

Therefore, establishing performance metrics to support overall firm performance is a challenging task that requires the partnership and collaboration. It was designed that a performance measurement for both single-echelon and complete supply chain systems by dividing assessment criteria into either 'Internal process efficiency' or 'Customer satisfaction' metrics. They then suggest five performance measures for a single-echelon supply chain management system; viz., order rate, FR, average inventory (AI), inventory variance, and the work in progress (WIP) variance ratio. Our research considers the inventory management from a corporate or a company-wide perspective. As forecasts for inventory management reflect the BWE, we apply a wider set of performance metrics as suggested by scientists. However, we focus on two of five measures suggested by scientists, namely, FR (which is relevant to customer service level) and AI (which is relevant to total inventory cost) criteria. These represent both internal process efficiency and customer satisfaction criterion and will be readily understood by many supply chain managers and staffs. The AI is the mean of inventory level during an inspection time (e.g., week or month).[22,23] It is frequently used in production and distribution systems to assess inventory investment and is treated as representative of internal process efficiency. The FR is a percentage of orders delivered on time and is representative of other customer satisfaction criteria. We propose the simultaneous use of both AI and FR measurement as an alternative approach (which we term the metrics approach hereafter). As mentioned above, the approximation approach should meet five criteria before used; therefore, the alternative approach proposed here can be used when the approximation approach does not satisfy five criteria outlined . Also, the metrics approach can be used for models highly impacted by the BWE and is therefore a robust measure. The results received from the metrics approach can be compared with the results from the existing research using total function to understand the differences between the two approaches. We propose a four-step method to accomplish this.[24,25]

IV. RESULT

We provided further insight into the development of the research trends when using and combining these characteristics for a perishable inventory management system. We showed that the current trend is towards the use of more sophisticated demand distribution in the models; however, single-echelon inventory management appears to be reaching a saturation point and researchers should increasingly focus their attention on multi-echelon models. Normally, in single-echelons, an approximation approach is used and we highlighted our concerns regarding the application of this approach to a wider system, such as an entire enterprise. A metrics approach was introduced for a perishable inventory management system and a process was proposed for comparing the performance and results from the metrics approach and approximation approach. [27]

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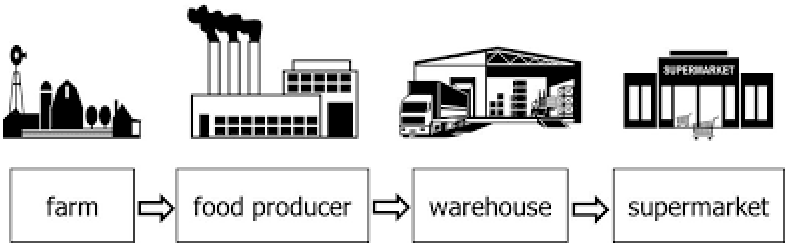

Non stationary demand

The metrics approach is used when decision is made from the view of total company or when the approximation approach does not satisfy the five criteria . The results contribute to inventory theory as this approach is more realistic as it incorporates multiple inventory characteristics and allows continuous improvement with performance metrics. The simulation results are used to develop heuristics, which provides quick solutions for changing in inventory characteristics (e.g., demand distribution) and business requirement (e.g., target FR). This research proposes a method to compare the replenishment decision determined using metrics approach with that from approximating the total cost or total profit function. Future research can apply this method to other types of perishable inventory management (e.g., multi-echelon, or multi-products). It was suggested metrics with five criteria and another research direction would involve considering performance metrics with a wider range of criteria for a comprehensive comparison that may present robust solutions to improve overall corporate performance.[28]

V. CONCLUSION

our goal is to propose an inventory model from the manufacturer's perspective with the following three key parameters in mind, which are given as the governmentcontrolled system parameters:

(1) how often the stockpile is refreshed and released to the open market,

(2) what is a suitable cost effective minimum inventory requirement, and

(3) how much should the government pay to the manufacturer for each pill stored in the stockpile.

These three parameters play key roles in determining the cost and revenue of the manufacturer. Through sensitivity analysis, we demonstrate how decision makers from the government's perspective can use the proposed model to set policy (determine the value of the above three parameters), and illustrate the possibility of reducing the cost to the government for the same level of VMI by leveraging the regular market demand.[26]

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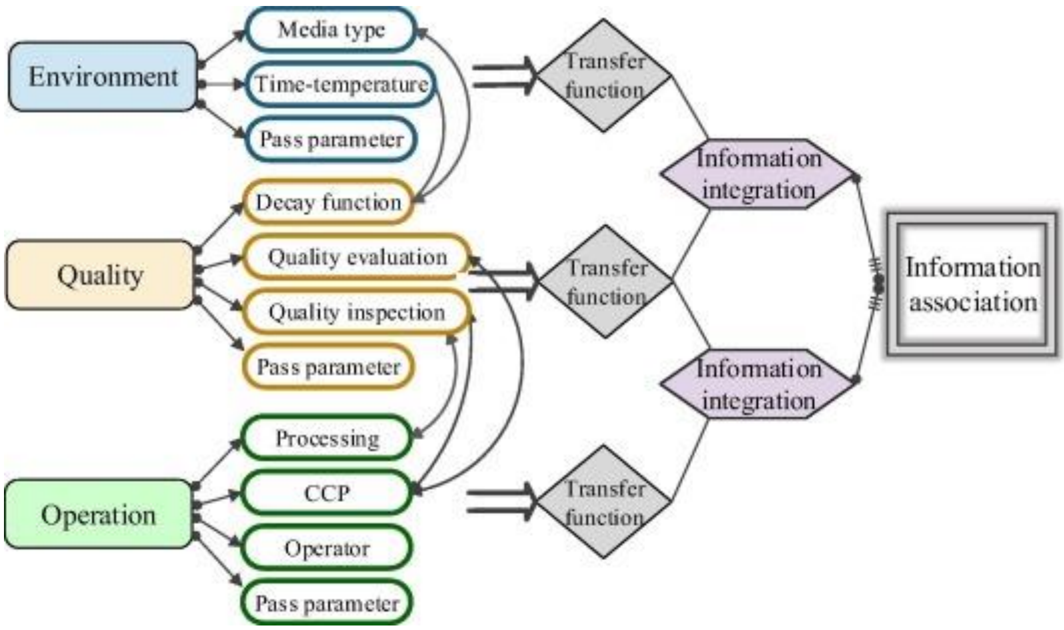

Supply chain of perishable products

In the SNS package, there are different medical supplies used for different emergency scenarios; for some single type of medical supplies (like antibiotics), there might be multiple suppliers. In this paper, we limit our study to a single manufacturer environment; the models for multiple manufacturers competing for contracts or how to model the strategy for the manufacturer-government interaction and negotiation are out of the scope of this study. In this work, we are concerned with a single fixed-life perishable inventory with large minimum stock requirement. Cipro is used as one example in our numerical experiments, but our model is general and could be applied to other inventory systems with similar characteristics. In such an inventory system, we need to satisfy two types of demand: the regular market demand and the minimum inventory requirement for emergency preparedness; and we aim to minimize the operational cost from the manufacturer's perspective. Such a large perishable inventory can be maintained by setting a fixed constant production rate to replenish the stock while using this inventory to satisfy the regular demand. This type of model, in the spirit of a just in time production shop, assumes that it can be optimal to produce at less than the maximum production rate.[27,28]

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