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Research Article

The Potential For Disruption To The Entire Inventory Management Function Schedule

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ABSTRACT

In the framework of working capital, inventories hold the most strategic position among business enterprises. It comprises the most substantial portion of current assets in the majority of businesses. The effective management of inventory within the context of working capital is particularly concerning because inventories obstruct about two-thirds of the current assets of cement manufacturers. In the event of a calamitous event, the initiatives worsen supply chain disruptions, thereby introducing a novel compromise between resilience in the face of disruptions and effectiveness in the course of regular operations. When making stocking decisions, operational disruptions are taken into account. These are different from demand uncertainties in terms of the risks they pose because they last longer and stop production flow. As a consequence, operational disruptions can be considerably more catastrophic, despite their low probability of occurring. We use stochastic simulation to find insights that can be used in managing inventory when there is a risk of disruption. These insights come from combining the newsvendor and order-up-to models, which look at the costs of uncertain demand, with catastrophe models, which look at both the cost of a supply disruption and the cost of recovery. These insights pertain to the management function schedule, which is the subject of discussion in this paper.

Keywords: Disruption, Operational disruptions, Management, Inventory

Introduction

Supply chain disruptions are common and can be caused by several factors, such as natural disasters, labour strikes, terrorist attacks, equipment malfunctions, supplier stock outs, or quality issues. Companies facing supply chain disruptions may encounter transportation delays and operational issues in their facilities, leading to inventory shortages. Despite efforts by corporations to mitigate them, certain interruptions are unavoidable. Therefore, firms must take measures to prevent the severe consequences of these interruptions. Companies have several strategies available to manage the risk of interruptions. One frequent strategy is to utilize inventories to mitigate the extra uncertainty. The primary focus on inventory management issues is determining the appropriate replenishment policy, specifying when, from whom, and how much to order (Atan, Z., & Snyder, L. V., 2012).
Managing inventory systems during supply disruptions may require increasing inventory levels above what would be needed in a disruption-free scenario. Managers may find the additional inventory undesirable due to the added holding expenses, especially when interruptions are often seen as infrequent occurrences. Conversely, the cost of proactively storing more inventories is typically much lower than the cost of an interruption in an unprotected system. Hence, there is a balance between the expenses incurred due to interruptions and the expenses incurred due to safeguarding (Ivanov, D., & Dolgui, A., 2022).
The optimal level of inventory a firm should maintain to mitigate interruptions relies largely on the nature of the disruptions. Inventory has been researched for many years as a means to mitigate the effects of unpredictable demand (Paul, S. K., et al., 2015). Essentially, there is no distinction between utilizing inventory to mitigate supply uncertainty and using it to mitigate demand uncertainty. Hence, it is worth considering if traditional demand uncertainty models may help address the challenges encountered by organizations during interruptions (Arreola-Risa, A., & DeCroix, G. A., 1998).

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Literature review:

Essuman, D., et al. (2020) explored the concept of operational resilience and its correlation with operational efficiency in various scenarios of operational interruption. Operational resilience is defined as a complex term with two independent components: disruption absorption and recoverability. These components are believed to impact operational efficiency differently depending on the level of operational disturbance. The study's hypotheses are examined using original data collected from a sample of 259 enterprises in a sub-Saharan African economy. The study utilized structural equation modeling to determine that both disturbance absorption and recoverability positively impact operational efficiency. The study shows that disruption absorption has a greater impact on operational efficiency under high operational disruption, whereas recoverability has a higher impact under low operational interruption. These findings contribute to a better understanding of how and when operational resilience affects operational efficiency by indicating that the particular disruption situations it faces have an impact on the effectiveness of operational resilience.

Gill, A., et al. (2014) examined the association between improvements in operational efficiency and the future performance of Indian manufacturing companies using a correlational research approach. 244 corporations were chosen from the top 500 companies on the Bombay Stock Exchange (BSE) for a five-year period spanning from 2008 to 2012. This study's results suggest that alterations in operational efficiency impact the future success of Indian manufacturing companies. This study adds to the existing research on the factors influencing changes in organizations' future performance. The results might benefit finance managers, operations managers, investors, financial management consultants, and other stakeholders.

Atan, Z., et al. (2012) discovered that supply chain disruptions are commonplace, encompassing both major and minor incidents. Major disruptions can arise from natural disasters, labor disputes, terrorist attacks, machine failures, supplier stockouts, or quality issues. Organizations that encounter disruptions in their supply chains may confront challenges such as transportation delays and facility malfunctions, both of which have the potential to cause inventory shortages. While organizations may implement preventative measures, certain disruptions are unavoidable. Therefore, to mitigate the severe consequences of these disruptions, organizations must implement protective measures. Organizations may elect to implement a variety of strategies in order to mitigate the risk of disruptions. One prevalent strategy is to employ inventory as a buffer against the added uncertainty. The primary objective of inventory management issues is to determine the most effective replenishment policy, which specifies when, how much, and from whom to order.

DeCroix, G. A. (2013) discovered that in an assembly system with a single final product and a generic assembly structure, there is a chance of random supply interruptions in one or more component suppliers or sub-assembly manufacturing processes. They offer a technique for breaking down the system into a comparable system that has certain subsystems swapped out for a series structure. This decrease makes it easier to calculate the best ordering strategies and may make it possible to compare the effects of disruptions in systems with various supply chain configurations. They pinpoint the ideal circumstances for a state-dependent echelon base-stock strategy. They base their proposal for a heuristic approach to solving the assembly system with interruptions on this outcome, and they conduct numerical experiments to evaluate its efficacy. They investigate several strategic issues with more numerical trials. For instance, they discover that selecting a supplier with a longer lead time might occasionally result in reduced system costs, which is counter to what is generally found in systems without interruptions. Additionally, they discover that a supplier with a shorter lead time benefits more from backup supplies than one with a longer lead time. Furthermore, they discover that, contrary to the approach that is usually favored when selecting backup suppliers for a single product, selecting suppliers whose disruptions are perfectly correlated results in lower system costs than selecting suppliers whose disruptions are independent. This is due to component complementarities. Gérard P. Cachon, an operations manager, approved this paper.

Mokhtar, S., et al. (2021) proposed a multi-period decision-making framework to assist procurement managers in developing an optimal supply inventory strategy, particularly when dealing with unpredictable supply conditions. The framework is structured around a procurement manager's goal of maximizing profit through strategic purchasing and stock management, utilizing financial options valuation approaches. The model utilizes an American options valuation method and a least squares Monte Carlo simulation technique to address the underlying dynamic programming problem. The model is meant to be resilient to several underlying stochastic variables, considering the numerous uncertain factors that influence inventory management choices in real-world scenarios. An illustrative case study utilizing data from a dairy supply chain is presented to demonstrate the potential use of the developed framework. The case study examines how a decision-maker can effectively integrate factors such as uncertainty in product demand and supply prices, expectations of supply disruption timing, discount rate, price shocks, and disruption duration into decision-making processes across various scenarios.

Methodology

This study employs a qualitative research technique and relies on secondary sources of information. The compilation will draw from several sources, such as published papers, journals, the internet, digital libraries, and other relevant resources. The data collected through these two methodologies, they will be used to develop various content analysing techniques.

Results and discussion

This study examines a two-stage supply chain for a single product with one supplier and retailer. Assuming Poisson distribution, the store confronts unpredictable demand. All-or-nothing stochastic disruption affects the supplier; hence, supply states can only be ‘on’ or ‘off’. The retailer must wait until the provider recovers before placing an order while supply is ‘off’. However, if supply is ‘on’ at the start of an inventory review period, the merchant can make an order and have it fulfilled. The merchant must establish the ideal base-stock level to minimize order, holding, and shortfall costs over an indefinite planning horizon. This study makes the following assumptions:

- The time to supply interruption is exponentially distributed, following a poisson process.
- Supply disruptions have an exponential distribution and do not need to be multiples of the review periods.
- The supplier can fulfil the retailer's order immediately upon receipt; therefore, the lead time is zero.
- Stationary demand follows a Poisson distribution.

The shortage is fully backlogged. This research uses Table 2 notations for mathematical derivation. The total cost function is determined using a renewal reward procedure to solve the problem.
If a disruption happens inside a review period and ends within the same period, the retailer can still place an order at the start of the following review period; hence, it is not deemed a disruption as it does not affect the ordering process. The above description of a renewal cycle states that each inventory cycle is exactly the duration of a review period, except for the last inventory cycle, which is disrupted. The duration of the interruption determines the length of the last inventory cycle in the renewal cycle.

Notation	**Descriptive terms**
Λ	Arrival rate of supply disruption
M	Parameter of the exponential distribution representing the length of a supply disruption
β	Demand rate
CO	Order cost per order
CH	Inventory holding cost per unit per time unit
CS	Shortage cost per unit per time unit
X	Random variable representing the time until an arrival of a supply disruption which is assumed to follow an exponential distribution with rate λ, i.e., the density function of X is $fx(x) = \lambda e - \lambda x$
Y	Random variable representing the length of a supply disruption which is assumed to follow an exponential distribution with rate μ, i.e., the density function of Y is $fy(y) = \mu e - \mu y$
N	Random variable representing the number of inventory cycles in a renewal cycle.
T	Length of an inventory review period
A/AT >	Random variable representing the length of the last inventory cycle in a renewal cycle.
D	Demand per time unit which is assumed to follow a Poisson distribution with mean β
DT	Demand of a review period
Da	Demand of the last inventory cycle in a renewal cycle when $A=a$
Z	Random variable representing the length of a renewal cycle
W	Random variable representing the time elapsed from the last order placing before a disruption occurs until the arrival of the disruption.
S	Base stock level
ILi	Ending inventory level of the ith inventory cycle (i = 1, 2, ..., n)
E[HCi]	Expected holding cost of the i inventory cycle (i= 1, 2, ..., n)
$E[SC_i]$	Expected shortage cost of the ith inventory cycle (i = 1, 2, ..., n)

E[TC]	Expected total cost per renewal cycle
E[TCU]	Expected total cost per time unit

This section will build the overall cost function for the inventory policy being considered. By applying the renewal reward theorem, we can calculate the predicted total cost per time unit.

$$E[TCU]=\frac{E[TC]}{E[Z]}$$

In which E[TC] E [Order cost per renewal cycle] E [Holding cost per renewal cycle]
+E [Shortage cost per renewal cycle]

Therefore, E [TCU] can be rewritten as:

$$E[TCU]=\frac{E[\text{Order cost per renewal cycle}] + E[\text{Holding cost per renewal cycle}] + E[\text{Shortage cost per renewal cycle}]}{E[Z]}$$

In order to derive the mathematical expression for the expected total cost per time unit, i.e., E [TCU], expressed the expected length of a renewal cycle, E [Z], is determined. In Section 3.2, the expected order cost per renewal cycle is determined. The expected holding and shortage costs in an inventory cycle without supply disruption is then determined in Section 3.3. In Section 3.4, the expected holding and shortage costs in the last inventory cycle of a renewal cycle where disruption occur are derived. From the results of Sections 3.1-3.4, the expression of E [TCU] is derived. Lastly, in Section 3.5, the modified expressions of the expected holding cost and the expected shortage cost in the last inventory cycle of a renewal cycle in which the length of a disruption period takes values only as multiples of the length of a review period are derived for comparison purposes in numerical experiments.

The estimation of the anticipated duration of a renewal cycle

It can be seen in table that $E\ [Z]\, E\ [N]\, T\ +\ E\ [A/\ A > T]$ so, in order to determine the expected length of a renewal cycle, we need to determine E [N] and i.e., the expected number of inventory cycles in a renewal cycle, can be derived as in Lemma 1 below

Lemma 1.

The expected number of inventory cycles in a renewal cycle can be determined as

$$E[N] = \frac{1}{1-e^{-T\lambda}}$$

Next, the expected length of the last inventory cycle in a renewal cycle where supply disruption occurs, i.e., E [A/A>T] can be determined as in Lemma 2 below.

Lemma 2

The expected length of the last inventory cycle in a renewal cycle where supply disruption occurs can be determined as

$$E\ [A_{A>T}] = T + \frac{1}{\mu}$$

From Lemma 1 and Lemma 2, the expected length of a renewal cycle, E [Z], can be determined as

$$E[Z] = (E[N]-1)T + E[A_{A>T}] = \left(\frac{1}{1-e^{-T\lambda}}-1\right)T + \left(T+\frac{1}{\mu}\right) = \frac{T}{1-e^{-T\lambda}} + \frac{1}{\mu}$$

Determination of the expected order cost per renewal cycle, the expected order cost per renewal cycle depends on the number of inventory cycles in a renewal cycle. This cost component can be determined as

E [Order cost per renewal cycle] = CO E [N]

From Lemma 1, the expected order cost per renewal cycle, E [Order cost per renewal cycle], can be derived as

$$E[Order\ Cost\ per\ renewal\ cycle] = \frac{C_0}{1-e^{-T\lambda}}$$

Determination of the expected holding and shortage costs in an inventory cycle without supply disruption

To approximately determine the expected holding cost and the expected shortage cost in an inventory cycle without supply disruption, the expected path approach is applied. This approach takes all possible scenarios that are likely to occur in an inventory cycle into consideration and the expected ending inventory level is used to help approximate the expected holding/shortage costs.

Determination of the expected holding and shortage costs in the last inventory cycle of a renewal cycle. To determine the expected holding cost and the expected shortage cost for this cycle, the expected ending inventory levels for these two scenarios will be first determined when the length of this cycle, A, receives the fixed value a, i.e.,, $E\ [IL_n|_{A=a}, IL_n \geq 0]$ and $E\ [IL_n|_{A=a}, IL_n < 0]$ respectively. It is noted that when $A = a$, the demand of the last inventory cycle will follow a Poisson distribution with rate $A\beta$. So,

$$E\ [IL_n|_{A=a}, IL_n \geq 0] = \sum_{\xi_a=0}^{S} (S-\xi_a)P\{D_a = \xi_a|_{IL_n\geq 0}\}$$

$$= \frac{\sum_{\xi_a=0}^{S} (S-\xi_a)P\{D_a = \xi_a\}}{P\{D_a \leq S\}}$$

And

$$E\ [IL_n|_{A=a}, IL_n < 0] = \sum_{\xi_a=S+1}^{\infty} (\xi_a - S)P\{D_a = \xi_a|_{IL_n<0}\}$$

$$= \frac{\sum_{\xi_a=S+1}^{\infty} (\xi_a - S)P\{D_a = \xi_a\}}{P\{D_a > S\}}$$

Lemma 4.
The expected holding cost and the expected shortage cost in the last inventory cycle of a renewal cycle can be determined as:

$$E[HC_n] = \int_T^{\infty} [\left[C_H\left(\frac{S}{2}\right)\left(\frac{S_a}{S+E\left[IL_n|_{A=a,IL_{n<0}}\right]}\right)\right] P\{D_a > S|_{A=a}\} + [C_H\left(\frac{S+E\left[IL_n|_{A=a,IL_{n\geq 0}}\right]}{2}\right) a]\ P\{D_a \leq S|_{A=a}\}]\ (\mu e^{-\mu(a-T)})d_a$$

And

$$E[SC_n] = \int_T^{\infty} [\frac{\left[C_S\left(\frac{E\left[IL_n|_{A=a,IL_{n<0}}\right]}{2}\right)\right]\left(aE\left[IL_n|_{A=a,IL_{n<0}}\right]\right)}{S+E\left[IL_n|_{A=a,IL_{n<0}}\right]}) \times P\{D_a > S|_{A=a}\}]\ (\mu e^{-\mu(a-T)})d_a$$

In which

$$E\ [IL_n|_{A=a}, IL_n \geq 0] = \sum_{\xi_a=0}^{S} (S-\xi_a)P\{D_a = \xi_a|_{IL_n\geq 0}\}$$

$$= \frac{\sum_{\xi_a=0}^{S} (S-\xi_a)P\{D_a = \xi_a\}}{P\{D_a \leq S\}}$$

$$E\ [IL_n|_{A=a}, IL_n \geq 0] = \frac{\sum_{\xi_a=0}^{S} (S-\xi_a)P\{D_a = \xi_a\}}{P\{D_a \leq S\}}$$

$$E\ [IL_n|_{A=a}, IL_n < 0] = \frac{\sum_{\xi_a=S+1}^{\infty} (\xi_a - S)P\{D_a = \xi_a\}}{P\{D_a > S\}}$$

$$P\{D_a \leq S|_{A=a}\} = \sum_{\xi_a=0}^{S} P\{D_a = \xi_a|_{A=a}\}$$

And

$$P\{D_a = \xi_a|_{A=a}\} = \sum_{\xi_a=S+1} P\{D_a = \xi_a|_{A=a}\}$$

from the general expression (1), we can rewrite the expression for the total inventory cost per time unit as follows:

$$E[TCU] = (C_0E[N] + (E[HC_i](E[N]-1) + E[HC_n]))/E[Z]$$

Conclusion and future suggestions

In the event that there is an interruption in supply, a company has to respond by adopting the appropriate method in order to prevent an excessive amount of lost demand. One reliable method that may be considered to assist in meeting demand at some point in the delivery interruption process is to ensure that the appropriate quantity of stock is adequately maintained. In this study, we intend to determine the most advantageous base-inventory stage of a periodic assessment of base-stock inventory coverage under the influence of delivery interruption. Our goal is to find the stage that would minimize the expected total stock value in accordance with time units. The length of a delivery disruption is modelled as a continuous random variable in the research that is presented here. This is in contrast to the majority of the previous research that has been conducted, in which the length of a delivery disruption was modelled as a discrete random variable that only accepts values that are multiples of the duration of an evaluation period. The findings of the comparison demonstrated that the utilization of a continuous random variable to estimate the duration of a supply disruption can prove to be an effective means of achieving more accurate and optimal inventory coverage. The contribution that our research has made is as follows: The results of numerous input parameters, such as the appearance fee of a supply disruption, the predicted length of a supply disruption, unit keeping price and unit shortage price, at the superior base-inventory level, and the minimum anticipated overall inventory fee, are utilized in the numerical experiments that are also carried out in order to analyze the results.
In the future, research should be conducted to expand upon the study that was provided in this paper in a variety of different ways. By considering replenishment lead time and doing an analysis of various inventory strategies, such as continuous assessment coverage or min-max stock coverage, further insights can be obtained. The circumstances in which an order could be partially completed in the event that there is a disturbance in the delivery process are similar to any other relevant problem. Additionally, in order to aid in the process of deriving a correct answer for the base-inventory level, approximation techniques or a heuristic designed specifically for the problem might be devised. It is of the utmost importance to mention that the utilization of a stock strategy by itself could not be the best choice for managing a delivery interruption, particularly in situations where the duration of a delivery disruption might be rather lengthy. In this kind of situation, it may be more advantageous to make use of a backup dealer or to source from a couple of different suppliers in order to protect against any shortage that may occur as a result of an interruption in delivery. The development of adequate supply contracts in situations when a backup provider is being explored or when only a number of suppliers are being utilized is another line of inquiry that shows promise.

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