

# Improving Order Quantity Model with Emergency Safety Stock (ESS)

Yousef Abu Nahleh, Alhasan Hakami, Arun Kumar, Fugen Daver

**Abstract**—This study considers the problem of calculating safety stocks in disaster situations inventory systems that face demand uncertainties. Safety stocks are essential to make the supply chain, which is controlled by forecasts of customer needs, in response to demand uncertainties and to reach predefined goal service levels. To solve the problem of uncertainties due to the disaster situations affecting the industry sector, the concept of Emergency Safety Stock (ESS) was proposed. While there exists a huge body of literature on determining safety stock levels, this literature does not address the problem arising due to the disaster and dealing with the situations. In this paper, the problem of improving the Order Quantity Model to deal with uncertainty of demand due to disasters is managed by incorporating a new idea called ESS which is based on the probability of disaster occurrence and uses probability matrix calculated from the historical data.

**Keywords**—Emergency Safety Stocks, Safety stocks, Order Quantity Model, Supply chain.

## I. INTRODUCTION

MANAGING supply chain network has become a vital global issue in the context of the severe effect of natural disasters and a wide variety of other reasons such as industrial plant fires, transportation delays, work stoppages, and it remains a largely unexplored area in research and practice. With increasing numbers of natural and man-made disasters, organizations are facing challenges due to limited number of available experienced logistics experts and the need for better coordination of those involved in vulnerable logistics networks. Moreover, companies running lean operations no longer have inventory or excess capacity to make up for production losses, resulting into rapid escalation of material flow problems to wide-scale network disruptions. The dynamic nature of the global supply chain environment dictates that the companies with resilient supply chains in the future will have a sustainable competitive advantage over other firms.

Over the past three decades, the number of reported disasters has increased fourfold. Around 6.1 billion people have been affected by disasters with an estimated damage of almost 2.3 trillion dollars [1]. An adequate level of mitigation

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measures and a coordinated post-disaster relief logistics management may help to reduce the loss of both human lives and economic damage. Time plays a critical role in the logistic plan, and it directly affects the survival rate in affected areas. This makes the task of logistics planning and supply chain management more complex than conventional distribution problems.

The emergency supply chain differs from the normal supply chain in many ways such as huge surge of demand with a short notice, damaged roadways, chaotic behavior of victims, break-down of infrastructure and communication lines, short lead time, major uncertainties about what is actually needed and what is available at the site, large volumes of critical supplies to be transported and so on. Under these critical conditions, delivering supplies becomes an extremely difficult task for the suppliers with limited or nonexistent transportation capacity. The design of a reliable emergency supply chain network is hampered by a lack of (1) knowledge about how emergent supply chains operate and interact, (2) methods to analyze and coordinate the flows of both priority and non-priority goods, and (3) scientific methods to analyze logistics systems under extreme conditions. Furthermore, forecasting and evaluating the reliability of transportation networks are significant for path selection in emergency logistics management under earthquake and other natural disasters. The reliability of arcs and nodes of a transportation network is time-varying under disaster conditions.

In major non-natural disasters such as terrorist attacks (e.g., September 11, 2001) or natural disasters such as the Hurricane Katrina of 2005 a disaster management structure organizer will face significant problems of emergency services and evacuation. In several disasters, the disaster area requests residents to be evacuated of the area and need to be moved to safe places as fast as possible, leading to a sudden and great surge of demands for emergency services.

Humanitarian relief organizations and NGO's are mostly non-profit organizations with the idea of providing critical services to the public in order to minimize the pain and sufferings after a natural disaster. According to UN Office for Humanitarian Affairs, there is an increasing human vulnerability in natural disasters, 244.7 million affected in 2011, and in complex emergencies 54 million in need of life-saving assistance in 2011. Furthermore, emergency management involves preparing for disaster before it happens, responding to disasters immediately, as well as supporting, and rebuilding societies after the natural or human-made disasters have occurred. It is essential to have comprehensive

emergency plans and evaluate and improve the plans continuously.

Supply chains are unprotected to diverse kinds of uncertainties that stalk from random yields, forecast mistakes or processing times. These uncertainties can be protected to a large extent by mechanisms such as safety stocks and time or arrangements of these [1], [2]. This paper focuses on the determination of safety stocks in inventory systems that face demand uncertainties disaster situation. When a specific supply chain is facing demand uncertainties, shortage can happen at all phases in the supply chain. Shortage can cause emergency shipments, loss of goodwill, or lost sales. Consequently, safety stocks should be kept to increase the service levels. Usually, safety stocks are determined based on theories from inventory principle [3]. Though, it is not clear how to define safety stock levels that cover uncertain demand in complex supply chains. This paper is structured as follows. Section II summarizes a literature review in this area, Section III discusses the problem explanation, and Section IV discusses the suggested method. Finally, Section V concludes the paper.

## II. LITERATURE REVIEW

One of the earliest studies for logistics management in relief operations was addressed by [4], for the increasing refugee population in Somalia. Subsequently, [5] addressed the need of logistics management in relief operations for the 1985 Mexico City earthquake. Some specific features of the emergency logistics problem were studied in the routing literature by [6]-[9], Hu [10]-[14], and [15]; however, the general logistics problem involving relief supplies distribution characteristics received far less attention. Further, [16]-[19] addressed the mathematical formulations for commodities transportation in emergency. Reference [20] extended the commodity logistics model to integrate the wounded evacuation and emergency medical centre location problems, and the logistics operations are illustrated by a concrete application on earthquake scenario. Further, [21] presented a meta-heuristic of Ant Colony Optimization (ACO) for solving the logistics problem arising in disaster relief activities. The logistics planning involves dispatching commodities to distribution centers in the affected areas and evacuating the wounded people to medical centers. Furthermore, [22] proposed a model to determine the number and location of distribution centers to be used in relief operations.

Humanitarian logistics, also called relief supply chain management, have gained attention due to an increasing number of natural and man-made disasters and the recognition of the central role of logistics in responding to these [23]. The needs are expected to increase another five-fold over the next fifty years' [24]. However, the literature in the area of humanitarian logistics is largely focused on handbooks and general procedures [25]. Reference [26] has reviewed the literature on disaster operations management, resulting in only 109 academic articles published in operations management related journals, indicating needs for more research on the

subject. The analytical techniques used in the field of operations research and management include mainly simulation, optimization and statistics. They concluded that most of the disaster management research was related to social sciences and humanities literature. References [27] and [28] discuss the need for speed and better coordination between those involved in the humanitarian logistics network. Logistics in humanitarian aid operations are highly dynamic, innovative and characterized by complexity of operational conditions and often politically volatile climate, high level of uncertainties in terms of demand and supplies, pressure of time and high staff turnover [29], [30]. Some studies such as [30]-[34], [24] emphasized that some supply chain concepts share similarities to emergency logistics and therefore can be successfully adapted in emergency response logistics. Reference [35] discussed the food security and humanitarian assistance among displaced Iraqi populations in Jordan and Syria. In a recent study, [36] highlighted pre-storm emergency supplies inventory planning. More research is needed to develop new models or new variants of old ones, especially in preparedness, response and recovery stages of the disaster management.

Although the literature in logistics management is extensive, the particular problem on the reliability of supply chains in emergency logistics planning has received little attention. Reference [37] studied the supply chain system reliability based on Markov process for normal business supply chains. Huang evaluated the reliability of railway emergency supply chain in China. Reference [38] proposed the GO methodology to analyze the transportation network reliability for emergency logistics; [39] recently studied the supply chain reliability in emergency situations in China. However, none of these studies provide an in-depth analysis of reliability of supply chains under natural disasters and vulnerability. Moreover, to my best knowledge, there is no research dealing with these two aspects of humanitarian and commercial logistics in an integrated manner which is the subject of this study, though such plan can significantly enhance the system-wide operational efficiency.

Reference [40] mentioned five reasons why the research in this area is very important. The first reason, [41] emphasized that the current method is not enough and that something has to be done to improve the emergency supply chain. Second, the cost in terms of both economic impact and human suffering is still growing. Third, there are many different organizations donating money and resource for the humanitarian / disaster relief event, so we have to find the best way to spend this money [42]. The fourth reason, how emergency supply chain systems can be organized to deal with uncertainty. Finally, by studying emergency supply chain we can deal with outcome rather than cost such as time because the time is very important in relief process specially the first 72 hours.

There is a wide quantity of literature available on inventory control models including uncertainties. We refer the reader to survey articles by [43] and [44]. Our study is within the field of Supply Chain Operations Planning [45]. The main objective

of Supply Chain Operations Planning is to organize the release of resources and materials in a supply chain system [45].

Two different methods exist for modeling the supply chain operations planning. The first method is created on multi-echelon stochastic inventory concept. In this methodology, demand that is challenged by the supply chain is designed as a random variable. The important choices of this methodology are the inventory positioning at the several stockpoints in the supply chain, the determination of safety stock points at the some stockpoints, and the distribution of amounts at inventory points where the product flow diverges. Thus, the determination of safety stocks is definite as part of the problem. Lead times input variables to the model and ability is expected to be measured through a grouping of order acceptance in the demand management role and a workload regulator function in the production unit. The logic is created on a line of study that has been introduced by [46].

The other method is based on mathematical programming values. In this approach, demand is introduced into the model as predictions for every period in the planning prospect. Safety stocks are input factors to the model and the important choices are the allocation of inventory amounts at the stockpoints in the supply chain. Lead times are both modeled as yield variables of the model (e.g., [47]) or are observed as deterministic response variables (e.g., [48]). Capacity restrictions are modeled clearly as aggregate limitations. The ideologies are based on investigation stemming from advanced MRP modeling [49] or from multi-period batch sizes problems ([50]; [47]). The values have been applied in commercial software, regularly using CPLEX solving logic (See also [51]). The two methodologies contrast also from a safety stock viewpoint. In this first method, safety stocks are definite as part of the problem, while in the second methodology safety stocks are input factors to the planning model, which have to be determined outside.

Reference [52] suggest a dynamic programming method to treat the problem of defining safety stocks in multi-stage inventory systems, supposing periodic evaluation base stock control strategies and normally distributed demand. Additionally, they assumed that no inside delays happen and that every stockpoint is satiating a service level limitation. More methodologies that are based on dynamic programming procedures can be found in [53] and [54]. Reference [55] debate the so-called guaranteed-service model for finding safety stocks in a multi-stage setting to cover demand uncertainties. They improve a model for sitting safety stocks in a supply chain where every phase is controlled by a base-stock strategy, assuming an upper certain for the customer demand level. Thus, the safety stocks set by their method cover demand understandings under the upper bounds. This hypothesis is essential to model certain service times between every phase in the supply chain and its customers. Optimisation approaches based on simulation of inventory systems are debated in [56]. Reference [57] perform simulation research to link the performance of five different inventory control strategies assuming wide-ranging fluctuations and periodic demand shapes. The consequences of

the simulations are some non-linear curves displaying the relation between the mean stock level and fill rate. Three of these five control strategies contain safety stocks, but the authors do not discuss how they find the safety stock bounds.

Reference [58] also performed simulation trials to assess some single-stage batch sizing procedures under demand uncertainty. In the studies of [59] the performance of three batch sizing rules in MRP systems is associated, assuming an uncertain demand process. The cost evaluations have been made by introducing safety stocks at every run to save the service levels at 95% and 98%. The essential safety stocks are defined by using the so-called Service Level Decision Rule (SLDR), which has been established by [60]. The SLDR is depending on linear regression analysis on replicated values of the following set of factors: the predictable time between orders, coefficient of variation of demand, and forecast errors. In order to reach the target service level.

Reference [61] proposed a so-called Safety Stock Adjustment Procedure (SSAP) to find goal service levels in simulation models. The method is based on the hypothesis that a Time Phased Order Point (TPOP) strategy is applied. Their simulation study goals to find the discrete possibility density function of the gross stock process. Based on this likelihood distribution, the safety stock is modified to confirm the definite target service level. Most methods make restricting assumptions about the demand process ([52], [55]) or do not clearly argue how they set the safety stock levels ([57], [62]).

### III. PROBLEM DEFINITION

Disaster related supply chain disruptions are increasing across all geographic regions, critically threatening the manufacturing operations across many of world's production facilities. There is also a direct correlation between disaster-related economic losses and limited investment in risk management. Thus, there is a need to achieve resilience in networked global supply chain and explain why building resilience is necessary and what kind of strategies and actions are required by manufacturers, suppliers, distributors and governments to achieve resilience and minimize risks. The objective is to reduce the economic loss due to inventory shortage caused by the disaster situation. This will be done by modifying the inventory management stock and safety stock by adding new concept called disaster safety stock. The outcomes will help manufacturers, suppliers and distributors of raw materials, parts and finished products in enriching their understanding of risks accumulated from years of development without attention to disasters and other vulnerabilities.

### IV. ORDER QUANTITY MODEL

#### A. Order Quantity Model with Safety Stock

A fixed order amount system perpetually controls the inventory level and places a new order when stock reaches some level,  $R$ . The risk of stock out in this model happens only during the lead time, or between the time an order is placed and the time it is received. As shown in Fig. 1, an order

is placed when the inventory point drops to the reorder point, R. During this lead time L, a variety of demands is possible. This range is determined either from a study of historical demand data or from estimation if historical data are not accessible [63].

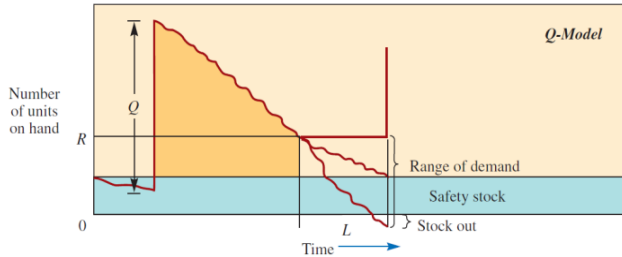


Fig. 1 Order Quantity Model

The quantity of safety stock depends on the service level wanted, as earlier discussed. The amount to be ordered, Q, is calculated in the normal way considering the holding cost, ordering cost, shortage cost, demand, and so forth. A fixed-order amount model can be used to calculate Q, such as the simple Q opt model before discussed. The reorder point is then set to cover the predictable demand during the lead time plus a safety stock determined by the wanted service level. Therefore, the important variance among a fixed-order quantity model where demand is identified and one where demand is undefined is in calculating the reorder point. The order amount is the same in both cases. The uncertainty part is taken into account in the safety stock [63].

The reorder point is

$$R = \bar{d}L + z\sigma_L \quad (1)$$

- R = Reorder point in units,
- $\bar{d}$  = Average daily demand,
- L = Lead time in days (time between placing an order and receiving the items),
- z = Number of standard deviations for a specified service probability,
- $\sigma_L$  = Standard deviation of usage during lead time.

### B. Modify Order Quantity Model

Recent natural disasters, such as tsunami in Japan, New Zealand earthquake, Taiwan earthquake, Thailand floods, Queensland floods, and a major fire accident at Nokia's supplier Plant in New Mexico, have disrupted the supply of raw materials, parts and finished products in a heavily networked global supply chain. In 2011, the economic impacts of the disasters were massive (US\$366 billion) and increased by 235% compared to the annual average economic damages from 2001 to 2010. Asia which is the manufacturing powerhouse of the world suffered the most damages (75% of global disaster damages), followed by Americas (18.4% and Oceania (5.6%). Thailand floods claimed seven major industrial areas and production facilities which manufacture approximately 25% of the world's supply of components for computer hard drives, leading to production delays and

disruptions at client businesses. Japan's Sony Corp flagged a record US\$6.4 billion loss impacted by the earthquake and flooding.

These disasters demonstrated how vulnerable the networked global supply chain is. Accordingly what was mentioned before the concept of Emergency Safety Stock (ESS), is necessary to make the manufacturing sector taken with the disaster situation.

The main objective for this method is to pre-plan for disaster before it happens. If the company has special kind of inventory for disaster situation they will be ready for any kind of problem. The disaster will not stop the operations. How to calculate the ESS:

$$ESS = \bar{d} \times P \times N \quad (2)$$

ESS= Emergency Safety Stock.

$\bar{d}$  = Average daily demand.

P= Probability that the disaster will happen (see the probability matrix).

N= Number of days the disaster will continue.

The probability matrix has been found by using the historical data for all the coordinating in the world. The following Table I shows sample of the probability matrix.

So the modified Order Quantity Model will be as follows in (3):

$$R_{modify} = \bar{d}L + z\sigma_L + \bar{d}PN \quad (3)$$

TABLE I  
 THE PROBABILITY MATRIX

Coordinating		Latitude						
		-34.8	-34.5	-33.4	-25.2	-22.57	-21.21	-21.13
Longitude	-176.23	0	0	0	0	0	0	0
	-176.17	0	0	0	0	0	0	0
	-175.20	0	0	0	0	0	0	0.0022
	-171.85	0	0	0	0	0	0	0
	-159.78	0	0	0	0	0	0.00053	0
	-71.13	0	0	0	0	0	0	0
	-70.57	0	0	0.00315	0	0	0	0
	-58.41	0	0.000623	0	0	0	0	0
	-58.17	0	0	0	0	0	0	0
	-57.67	0	0	0	0.0046	0	0	0
	-56.17	0.00469	0	0	0	0	0	0
	17.08	0	0	0	0	0.0024	0	0

### V. CONCLUSIONS

In this paper, we introduced a new concept in Order Quantity Model called Emergency Safety Stock (ESS) and an approach to determine it in disaster situations that face demand uncertainties. The main objective for this method is to pre-plan for disaster before it happens. If the company has special kind of inventory for disaster situation they will be

ready for any kind of problem. The disaster will not stop the operations. Accordingly what is mentioned before the concept of Emergency Safety Stock (ESS) is necessary to make the manufacturing sector taken with the disaster situation. Fig. 2 summarizes the concept of Order Quantity Model from the start in figure part A to the end with the ESS concept.

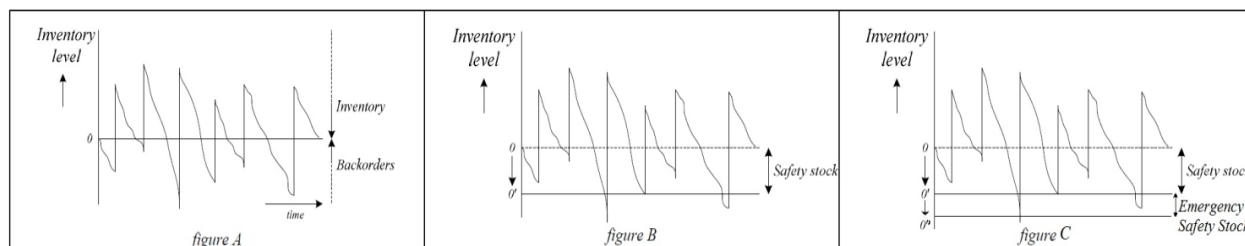


Fig. 2 Order Quantity Model (A: without safety stock, B: with safety stock but without ESS, C: with safety stock and ESS)

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