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Value of disruption information in an EOQ environment

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ABSTRACT

We consider an infinite horizon, continuous review inventory model with deterministic stationary demand where supply is subject to disruption. The supply process alternates between two states randomly: one in which it functions normally (ON-period) and one in which it is disrupted (OFF-period). In this setting, we seek the value of disruption information which enables the buyer to place “disruption orders” at the beginning of OFF-periods. Utilizing renewal theory, we derive the total expected cost and characterize the optimal regular order-up-to level together with the order-up-to level for disruption orders. We also conduct an extensive numerical analysis and compare the results with the model with no opportunity of disruption orders. We observe that if the shortage cost is relatively high, and the disruption risk is significant (in terms of duration and/or frequency), placing a disruption order reduces the expected total cost significantly.

1. Introduction

Supply uncertainty has a drastic effect on supply chains, causing high operating costs and low customer service level. Forms of supply uncertainty can be categorized as follows: Yield uncertainty (the output of a manufacturing process is a random variable that depends on the order quantity), capacity uncertainty (the supplier’s delivery capacity or the firm’s manufacturing capacity is a random variable), lead time uncertainty (the order or processing lead time is stochastic), input cost uncertainty (the procurement costs incurred by the buyer is stochastic) and supply disruptions. Snyder et al. (2014) state that “Disruptions are random events that cause a supplier or other element of the supply chain to stop functioning, either completely or partially, for a (typically random) amount of time”. It is commonly known that supply disruptions can be caused by several and serious reasons which (Atasoy, Güllü, & Tan, 2012) categorize under two groups:

- Unpredictable disruptions: natural disasters, terrorist attacks, accidents, labor actions, breakdowns, transportation disruptions, order cancellations.
- Predictable disruptions: price inflation, capacity restrictions and scarcity of some resources at the supplier. In this case supplier may choose to allocate his restricted capacity to other manufacturers or products, or he cannot produce at all, leaving all of his customers not satisfied.

There are numerous examples on the drastic effects of supply disruptions. In developing countries, the local utilities may cut off the supply at random times for random durations due to excessive demand for electrical energy (Parlar & Perry, 1995). Nokia and Ericsson suffered a several-week disruption of computer chips that are used in mobile phones, which was caused by a lightning at one of Philips Electronic facilities in New Mexico. Ericsson lost 1.68 billion dollars for its mobile phone division and retreated from the phone handset production market in January 2001, while Nokia managed to cope with the effects of the disruption (Xia, Yang, Golany, Gilbert, & Yu, 2004). Apple, Motorola and Sony also make public that they struggled problems with meeting their demands due to shortages of key components caused by unforeseen circumstances in 1995, 1999 and 2000, respectively (Hendricks & Singhal, 2003). Hendricks and Singhal (2005) report over 800 cases of disruptions in supply chains and conclude that “firms suffering from supply chain disruptions experience about 30% lower stock returns than their matched benchmarks”.

The mitigation strategies against supply disruptions are similar to the ones against demand uncertainty. Tomlin (2006) discusses three categories of mitigation strategies for supply chain disruptions: (i) inventory, (ii) sourcing, and (iii) acceptance.

In practice, suppliers usually have better information than buyers about the likelihood and timing of disruptions as they have a better understanding of capacity restrictions, scarcity of resources, pipeline stocks and agreements with other buyers. Furthermore, buyers would be unaware of disruptions until they place an order and see that the order cannot be fulfilled. Hence, disruption information may be very valuable to the buyer as it would enable

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her to place an order just before disruption occurs (if predictable by the supplier), or just when disruption occurs before other customers.

In this study, we aim to analyze the value of disruption information that will provide an additional order opportunity for the buyer when the supplier gets disrupted. That is, we investigate the benefits of a setting to the buyer where the buyer gets informed when disruption (i) occurs or (ii) is to occur, hence it has an opportunity to place an order (i) just as or (ii) right before the supplier's state turns OFF. Note that in case (i), a disrupted supplier is likely to face serious limitations in fulfilling an additional order. In case (ii) on the other hand, there is an inherent uncertainty in a "disruption to occur" as to whether it will occur and when. Such complexities are not handled in our model and we treat both cases similarly. However, it should also be noted that our objective is to identify insights about the conditions under which such a disruption order opportunity would be worthwhile to seek, and we opt to consider a stylized model assuming an uncapacitated supplier with no lead time and certainty in disruption information. We realize that the results that we generate on the value of disruption orders would be upper bounds for more realistic settings. Besides, we believe that our setting represents a realistic environment under certain conditions. For instance, for the first case (the buyer is informed when disruption occurs), the supplier might give priority to the buyer in allocating its on-hand inventory at the time of the disruption, which does not impose additional restrictions on the supplier. For the second case (disruption to occur), the supplier might have prior information with certainty, such as planned maintenance, labor strike, or raw material shortages.

We believe that such an analysis will also contribute to the understanding of the value of establishing long-term, close relations between the supply chain partners. For this purpose, we consider an infinite horizon, continuous review inventory system subject to disruptions. Specifically, we model the supply process as a Continuous-Time Markov Chain (CTMC) alternating between ON and OFF-periods. Demand is deterministic; lead time is zero; the replenishments are instantaneous and complete. Planned backorders are not allowed. Only during OFF-periods, unsatisfied demand can be backordered. The cost components we consider are fixed order cost, inventory holding cost and backorder cost. In this setting, we aim to assess the value of an additional order opportunity that can be placed just before or whenever the supplier is disrupted. For this purpose, we consider an inventory policy consisting of two order-up-to levels: regular order-up-to level which is the order-up-to level for orders placed when the supplier is ON, and disruption order-up-to level which is the order that may be placed at the beginning of an OFF-period. In order to assess the value of disruption information, we compare this model to the model that the buyer does not have any opportunity to place an order in the case of a disruption. This "no disruption order opportunity" model is first studied by Parlar and Berkin (1991) under the assumption that unsatisfied demand is lost whereas we consider the backordering situation. To our knowledge, this study is the first one in the literature that investigates the value of disruption information in an EOQ environment which enables the buyer to place an order in case of a disruption. We also conduct an extensive numerical analysis in order to find the value of disruption information and to illustrate some examples. Our findings indicate that disruption information prevents the buyer to inflate its regular orders, which helps decrease the bullwhip effect as it enables smaller and more frequent orders. As a result, disruption information may lead to significant savings in expected costs, up to 90% as we observed in our numerical study. We observe that the savings do not diminish even when there is a limitation on the disruption order levels. However, the buyer may choose not to use the additional order opportunity when the backorder cost is relatively small and/or the expected duration of the disruption is short. We also offer heuristic solution approaches that provide straightforward and easy-to-comprehend solutions as finding the optimal order-up-to-levels require an exhaustive search and the results are not easy to interpret. Through numerical experiments, we observe that the heuristic approaches perform quite well.

The remainder of the manuscript is organized as follows: In Section 2, literature on supply disruptions and the value of disruption information is presented. The model without disruption information is discussed and analyzed in Section 3. Section 4 includes the analysis of the model with disruption information. In Section 5, the results of the numerical study are presented. Finally, summary of the study and future research suggestions are given in Section 6.

2. Related literature

There is a considerable, growing body of literature on supply disruptions. Our aim in this section is to locate our work in this literature rather than providing a comprehensive review. For an extensive review, we refer the reader to Snyder et al. (2014). We limit our discussion of supply disruptions to the deterministic demand case.

Parlar and Berkin (1991) introduce EOQ with disruptions (EOQD). They consider an EOQ environment and assume that the unsatisfied demand is lost. The supply alternates between ON and OFF statuses whose durations are governed by general probability distributions. They use renewal reward theorem to compute the average expected cost per unit time. However, Berk and Arreola-Risa (1994) point out that Parlar and Berkin (1991) implicitly assume that there is a stockout in every cycle, which is not necessarily the case. Second, they argue that Parlar and Berkin (1991) derive the expected shortage cost per unit per time which is not appropriate in the case of lost sales. Berk and Arreola-Risa (1994) define a cycle as the time between receipts of successive orders; each cycle begins with exactly the same inventory level. Both ON and OFF-periods are exponentially distributed. Snyder (2014) approximates (Berk & Arreola-Risa, 1994) cost function assuming that ON-periods last longer on the average than OFF-periods. His approximation ignores the transient nature of the system and works under any distribution for ON and OFF-periods' lengths as long as the system reaches steady state. Qi, Shen, and Snyder (2009) consider disruptions at the supplier as well as at the retailer. If disruption occurs at the retailer, then it loses its all ON-hand inventory. They conclude that the disruption at the retailer have bigger impact on the expected total cost than the disruption at the supplier. Atan and Snyder (2014) provide a summary of the research on EOQ models with disruptions.

It is known that placing an order when the inventory level hits zero (ZIO) is optimal under the classical EOQ environment. Yet, it may not be the case in EOQD. Parlar and Perry (1995) study an EOQD model treating the reorder point as a nonnegative decision variable. ON and OFF-periods are exponentially distributed. Parlar and Perry (1996) continue with single, two and multiple suppliers having independent and exponentially distributed ON and OFF times. In the case of more than one supplier, buyer can choose any combination of them to place orders since the cost structure is the same for all suppliers. They conclude that as the number of suppliers increases, the objective function converges to the classical EOQ model with no disruption. Gürler and Parlar (1997) consider a continuous review model with two suppliers where the suppliers' ON-periods follow Erlang distribution and OFF-periods follow a general distribution. They model availability of the suppliers as a semi-Markov process. An order is placed at either of the two suppliers, when the inventory level drops to the reorder point. They conclude through several examples that the state-dependent inventory policy dominates (Q, R) policy. Heimann and Waage (2007) extend the