Int. J. Production Economics 171 (2016) 478–486

Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

Analysis of production systems with potential for severe disruptions

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ARTICLE INFO

Article history:
Received 13 January 2014
Accepted 1 September 2015
Available online 25 September 2015

Keywords:
Production interruptions
Produce to stock
Food processing
Correctional industries
Simulation
Bayesian methods

ABSTRACT

Organizations often have to make production capacity decisions in a setting where production disruptions occur. This presents managers with a combination of strategic capacity decisions and operational inventory management options to manage disruptions. This paper uses Bayesian methods to analyze operational data where data on parameters required in logistics models are unavailable, then models production and inventory management in systems that have the potential for major disruptions. The produce-to-stock with production disruptions model is applicable to systems where the decision on production rate is coupled with the setting of the base stock level when production disruptions are possible. The model is applied to a proposed food processing facility at a correctional institution that is subject to disruptions due to safety and security issues.

1. Introduction

One of the goals of correctional institutions is to prepare inmates for their eventual release into society by providing some form of productive employment while interred. In Pennsylvania, United States, the Pennsylvania Correctional Industries (PCI) manage industries within state correctional institutions. By state law, prison based industries sell products only to other state agencies, such as other correctional institutions, government agencies, and other tax-supported entities (Pennsylvania Correctional Industries, 2013). One industry under consideration is food processing. However, these industries must still be operationally and financially viable. In the case of food processing, this means the supply chain network must still provide a guaranteed service level to its customers at a cost competitive with outside suppliers.

Many logistics models that allow for supply to be stochastic assume that an outside supplier can fill an order when a disruption is resolved, such as Snyder (2015). In the case of a correctional institution food processing facility the production capacity is limited. Traditional models that address supply chain disruption focus on external suppliers and assume that when the disruption is complete, the external supplier will resolve the disruption. In the case where production is internal to the system the system uses production capacity to recover from the disruption so traditional models used to analyze supply disruptions do not address this situation.

This paper begins with an analysis of available data on lost time events using Bayesian methods to determine parameters for use in the production and inventory model. Then the paper formulates the production and inventory policy problem as a produce-to-stock system with production disruptions and lost sales. This production and logistics problem will then be analyzed through a simulation model which accounts for the variation in demand due to an uncoordinated order scheduling process.

While this paper is motivated by a specific real-world example, the situation where the production and logistics decisions need to be made in environments where the historical data collected was not intended for use in supporting operations and the cost structure of the proposed operations is in flux is a common one. This paper contributes to the literature by applying Bayesian methods to production and logistics problem and representing the production and logistics decisions as tradeoffs between production costs, inventory costs, and service level.

2. Problem description

2.1. Problem setting

Employment in correctional industries (CI) has been linked to reducing recidivism through addressing one possible cause of incarceration and recidivism: lack of job skills (Sedgley et al. 2010). Studies note that the work experience and skills of prisoners also typically are well below that of the general population. The lack of work experience and skills, when combined with low education levels and difficulties in obtaining employment upon release, can contribute to a cycle of unemployment that increases the likelihood of further criminal behavior (Lawrence et al. 2002). In addition, CI provides correctional departments a commitment to

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http://dx.doi.org/10.1016/j.ijpe.2015.09.014
0925-5273/

employ inmates, which reduces the supervisory burden on correctional staff. The inmates are provided meaningful training and work experience while gaining a positive work ethic and earning modest wages for their labor. In 2006, nearly 83,000 inmates worked for CIs, compiling more than 126 million work hours and earning more than $136 million in wages (Brown, 2010). A comprehensive study funded as part of the Second Chance Act of 2008 found that the odds of obtaining employment post-release among inmates who participated in correctional education (vocational or academic) was 13 percent higher than those who had not participated (Davis et al. 2013).

Some attractive features include the ability to train inmates in skills similar to those used by potential future employers in the commercial food processing businesses and the potential cost savings from processing food within the correctional system. For example, at a meat processing plant at the Pickaway Correction Institution in Ohio inmate workers earn certificates in carcass fabrication, retail cut identification, food safety, and hazard analysis. Producing meat products within the correctional system saved the State of Ohio approximately $3.3 million per year in food costs for correctional institutions (Bischoff, 2010).

A key difference in production analysis for meat production within a correctional institution that is not a consideration for other meat production facilities or for other products produced within correctional industries is the effects of lost time on the production and delivery process. Lost time occurs when production is interrupted due to the operational requirements of the institution. These can be due to administrative requirements such as the need to provide services to inmates or it can be due to security concerns, such as an institutional security lockdown. While many interruptions are short term, lasting no more than a few hours, security lockdowns can last up to several days depending on the incident. In contrast to other products that are produced within correctional institutions can tolerate slippages in delivery schedules, the institutions that would be the primary customers of a food processing plant require a stable supply of product. Therefore, the primary objective for this system is to minimize stockouts.

In contrast to most of the literature on managing supply chains in the presence of disruption, there is one characteristics of PCI meat production that makes it different than similar examples in the literature. The production, storage, and demand are all internal to the PA Department of Corrections and production capacity and inventory policy can be thought of as coordinated decisions. Mitigation measures may be employed at the production facility, intermediate inventory locations, or at end demand points. This is in contrast to many models where the production is done by an external supplier or the production capacity is considered as fixed.

An additional deviation from available models is the demand process. The demand process is currently based on the order schedule, which is neither random nor constant. This precludes using analytical models which either assumes constant demand or that the demand follows a random process.

Therefore, to model the system as part of a study to determine the feasibility of a prison based food processing operation, it is important to evaluate the ability of the facility to provide ongoing delivery of food products even in the presence of production interruptions in a cost effective manner.

In the scenario under consideration, we can consider two types of decisions that provide what Tomlin (2006) regards as operational mitigations. First, the base stock inventory level can be chosen. Second, because the production facility capacity has not yet been determined, the production capacity can be sized so that the system can recover from a disruption more rapidly.

One operational contingency option that will not be considered here is the use of reduced production started in the case of a prolonged disruption. In a correctional institution, long term disruptions are generally due to security related events. It may be possible to restore limited production by allowing a portion of the labor force to return to work before the disruption is over. However, this is not desired and it is considered important to determine that this measure will not be requested often before this production facility will be authorized. As the modeling and analysis was being done as part of a feasibility study, the cost structure of the production facility was uncertain. Therefore an optimization would be inappropriate. Instead, the effects of production and inventory capacity decisions will be presented as tradeoffs between production capacity, inventory costs, and service level that could be made by the decision makers.

2.2. Literature review

Snyder (2006) provides an overview of the high cost of supply disruptions in lost productivity, loss of goodwill, and damage to facilities. They note that supply uncertainty and demand uncertainty in supply chain have several similarities, and that firms have used similar strategies such as holding inventory or using multiple suppliers to protect against both supply and demand uncertainty. However, they also note that many of the lessons learned for addressing demand uncertainty do not hold for supply uncertainty. Vakharia and Yenipazarli (2009) look at potential responses to supply chain disruptions based on their classification. Classifications include acts of nature or acts of humans, the point the disruption occurs in the supply chain life cycle, the type of disruption, and the managerial impact. Snyder et al. (2014) provide a review of OR/MS (quantitative) models for use in managing supply chain disruptions. The base model is one where supplier has alternating functional (up) and disrupted (down) periods. They identify five mitigation strategies from the literature:

1. Inventory – holding inventory to protect against possible future disruptions.
2. Routine sourcing – source products from more than one supplier. For the strategy of routine sourcing, when there is a disruption, the continued receipt of routine orders from the other suppliers is sufficient to reduce the impact of the disruption.
3. Contingent rerouting – similar to routine sourcing, there are multiple suppliers. However, in this strategy in the case of disruption, additional orders are made to the non-disrupted sources to mitigate disruption.
4. Demand substitution – if one product is out of stock due to a disruption, a firm may attempt to shift demand to a product that is available.
5. Financial mitigation – purchase insurance to protect against disruption, or provide subsidies to supplier in order to stabilize the supply base.

   Finally, there is a sixth strategy which is to do nothing:

6. Acceptance – accept the risk of disruptions and the consequences.

The literature on inventory policies in the presence of supply or production disruptions can be grouped into three groups. First is base stock policies that look at disruptions from an external supplier. Second is papers that look at stochastic disruptions with fixed demand and capacitated production. Third is models with stochastic demands.

2.2.1. Base stock policies with supplier disruption

Some models that address the issue of supply chain disruptions are based on the continuous review economic order quantity (EOQ) and periodic review newsvendor models. Berk and Arreola-Risa (1994) build on the work of Parlar and Berkin (1991) to extend