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Supply Chain Management of the Strategic National Stockpiles

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1. Overview 1
2. Research Accomplishments 2
3. Applied Relevance 3
4. Collaborative Projects 5
5. Research Products 5
5.1. Publications and Reports 5
5.2. Presentations 5
5.3. Models, Databases, and Software Tools and Products 6
6. Education and Outreach Products 6

1. Overview

The Strategic National Stockpile is part of the federal response to a bio-terrorist attack on the United States and it is composed of a combination of vaccines, prophylaxis, and medical supplies aimed at minimizing the damage of the attack. The SNS is currently divided into "Push Packages" directly managed by the government, which constitute about 20%, with the rest as Vendor Managed Inventories (VMIs) in control of pharmaceutical companies. The Push Packages constitute a stock that can be rapidly deployed and contains a set mix of supplies effective for a broad range of attacks. The VMI provide additional flexibility and cost efficiency as it can deploy the specific medicine to combat a bio threat. Given the possible biological and chemical threats facing the nation and the limited budget to set up the SNS, the effective allocation of these resources in designing the SNS are key in managing the risk posed by these threats. The purpose of this research is to develop models that can aid decision makers to effectively design and manage this complex supply chain process under a given funding level.

Currently, the SNS policy allows manufacturers to sell the pills at a predefined date prior to expiration rather than let the drugs spoil; however, considering the fact that the size of the stockpile is huge compared with the regular market demand while the drugs are so close to their expiration date, the potential salvage value is low. From the manufacturer's perspective, if it can apply a more sophisticated inventory holding policy which allows the constant usage of the stockpile to meet the regular market demand and refill with new production at the same time to maintain the minimum stockpile requirement, then the firm can save on the total cost in maintaining the stockpile inventory, hence making it possible to further reduce the price charged to the government. From the government's perspective, if it allows firms to sell the pills earlier, there is an opportunity to capture a significant amount of salvage value for the unsold stockpile. The unique challenge of this problem lies in efficiently maintaining a minimum level of perishable inventory.

Since the stockpile contains perishable items which may never be called to use by the federal government (in cases where no terrorist attack occurs), the key challenge from both the government's and manufacturer's perspective is determining (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. Through sensitivity analysis, we demonstrate how decision makers can use the proposed model to set policy, and illustrate the possibility of reducing the cost to the government for the same level of VMI by leveraging the regular market demand. On a potential anthrax attack scenario using the drug Cipro, we show the cost effectiveness of developing a model that considers both the regular market demand and the minimum inventory requirement simultaneously as opposed to operating the supply chain as two separate systems: one for the regular market demand and another for the minimum inventory requirement of the stockpile.

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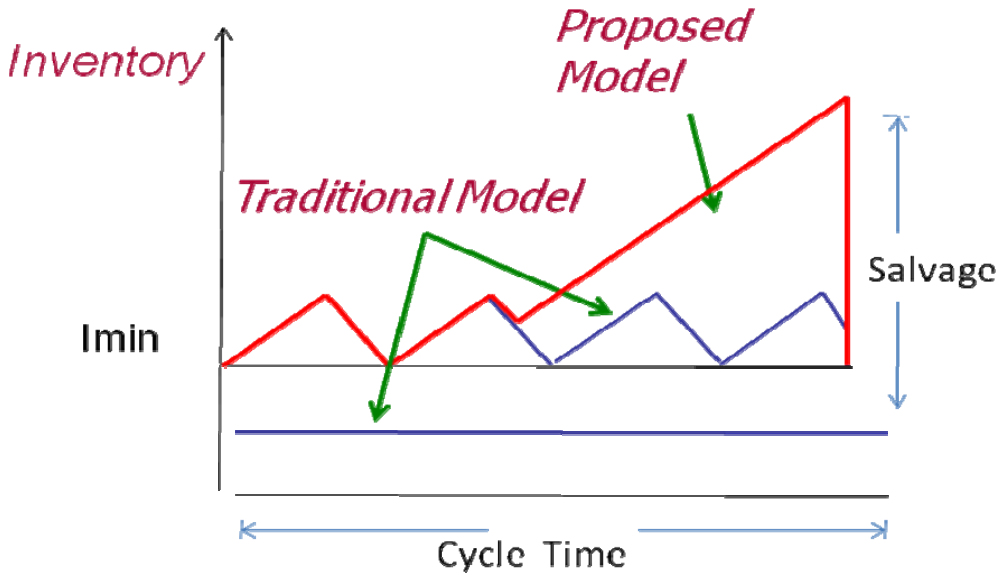
Our proposed model compared with the standard model of separating these two demand domains shows a significant cost saving of around $33 million per year, which saves about 30% of the cost to the standard model.

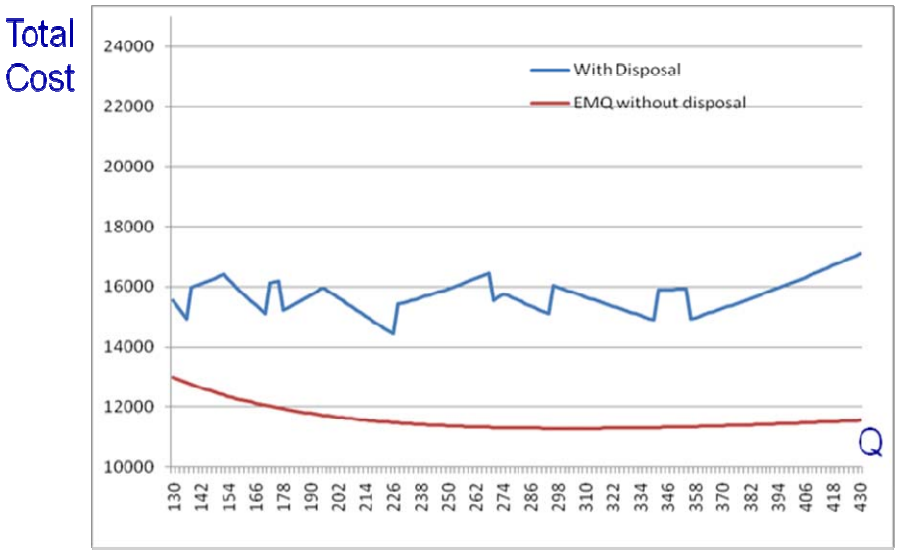
2. Research Accomplishments

The traditional EMQ (Economic Manufacturing Quantity) model can be readily extended to address the perishability property of a stockpile with no minimum inventory requirement by properly upper-bounding the EMQ cycle to guarantee that the inventory is consumed within its shelf-life. In the case that the minimum inventory required is significantly smaller than the total regular market consumption over the shelf-life of the drug, a tighter limit on the EMQ cycle that also takes into account the freshness of the minimum inventory is sufficient. However, when the minimum inventory is comparable with the total regular market consumption during the shelf-life, a trivial extension to any of the existing perishable inventory policies is no longer adequate. It is therefore imperative to develop a new inventory policy specially geared to the perishable VMI system for the SNS, which not only satisfies the minimum inventory requirement but also minimizes the operational cost of maintaining such a system by incorporating the regular market demand. Hence, in this research, we aim to propose a single inventory system which satisfies the two types of demand: the regular market demand and the minimum inventory requirement for emergency preparedness, which minimizes the operational cost from the manufacturer's perspective. In this work, we modeled the perishable inventory management problem with a minimum inventory volume constraint as a modified economic manufacturing quantity (EMQ) model. The key distinction between our model and the prior work is that we integrate the two separate demand domains into a single model whereas a traditional model would consider a separate model for each demand domain.



We discussed the policies and assumptions adopted in this model from both the regular perishable inventory management context and the special constraints on the minimum stock size and maximum inventory cycle length enforced by the large-scale emergency response context.
The total cost was decomposed into four components: inventory holding costs, fixed ordering costs, purchasing costs and salvage costs. With the aid of inventory plots, we formulated the problem to minimize the total relevant cost with respect to the production batch size as an unconstrained non-

continuous non-differentiable optimization problem. We proved the existence of the local as well as global minimum of the total cost with respect to the order quantity. Hence, an exact solution procedure was proposed and its complexity was proved to be pseudo-polynomial, hence making it computational possible to obtain an optimal solution to the problem.



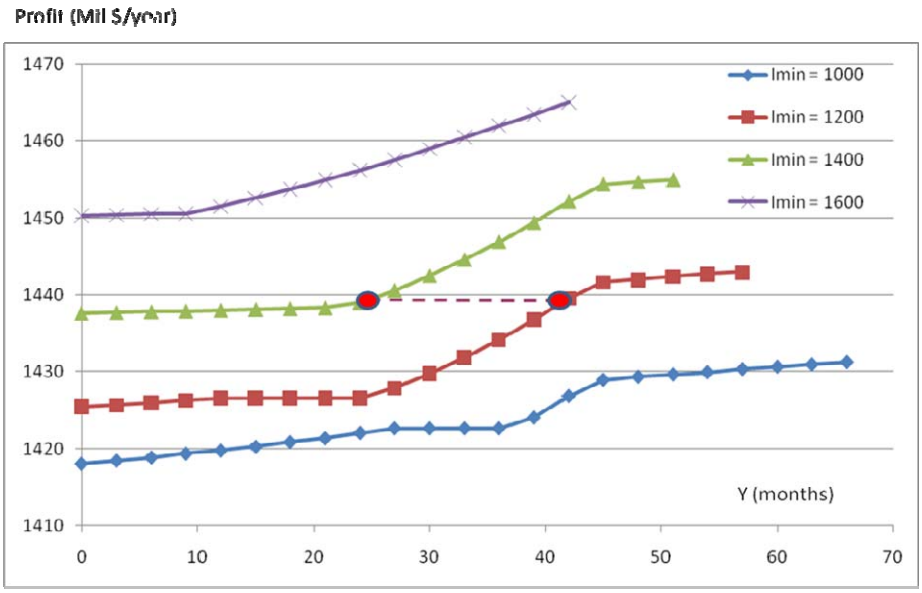
At the local level, rapid and efficient wide-scale distribution of medical supplies plays a critical role in assuring the effectiveness in managing the risks of large-scale emergencies such as bio-terrorism. Important issues in the design of such an efficient distribution network involve deciding how to route distribution vehicles and how to manage these inventories. To efficiently distribute the medical supplies for large-scale emergencies, a two-stage solution approach was proposed by solving a stochastic routing problem in the first planning stage and a deterministic scheduling problem in the second operational stage. We formulated a mixed integer model which incorporated the routing with profits and the traditional complete routing for the first time to address the planning stage problem. A chance-constrained approach was applied to handle the uncertainty in both demand and travel time in the stochastic planning stage model. Three recourse strategies were implemented and compared for the operational stage. We developed a tabu heuristic and approximated knapsack heuristic to solve models in both stages. Numerical experiments were conducted to evaluate our models and solution approaches based on simulated large-scale emergencies.

3. Applied Relevance

In a potential anthrax attack, the federal government is prepared to treat 10 million exposed persons. This represents a stockpile of 1.2 billion Cipro pills (the treatment regimen is two pills a day for 60 days), as the minimum inventory requirements, I_{min}, in our experiments. According to the *Cipro Pharmacy.com* website http://www.ciprofloxacinpharmacy.com/active.html "Cipro has a shelf life of approximately 36 months. However, material has been and is currently being tested through the DOD/FDA Shelf Life Extension Program (SLEP) and has received extensions up to 7 1/2 years from original expiration date and some lots have received up to 9 years from original expiration date. Material shows no signs of deteriorating based on yearly test." Based on the above statement, we used 9 years (108 months) as the shelf-life of the drug, which indicates that the government would pay for the production and storage of I_{min} every 9 years. We define a parameter Y to represent the flexibility that the government gives to firms, which is defined as the number of months before the expiration that the government allows I_{min} to be sold.

We estimated the parameters in the modified EMQ model for a potential anthrax attack scenario from various sources and used them to compare the proposed model with a standard model to show a significant cost saving of running our system as around 33 million US dollars per year, which saved about 30% of the cost to a standard model. We performed sensitivity analysis on some government controlled parameters in the system and observed that at a given profitability level of the firm, there are trade-offs between the less amount paid by the government to firms (either by reducing the Imin requirement or by reducing the unit price the government pays the firms for production and storage, pgov, with the higher flexibility the government allows to firms, longer time before the expiration to salvage the pills).

Through sensitivity analysis, we demonstrated how decision makers can use the proposed model to set policy on Imin, pgov, and Y, and illustrate the possibility of reducing the cost to the government for the same level of VMI by leveraging the regular market demand. The plot below illustrates an example of the performed sensitivity analysis.



- For any fixed flexibility *Y*, the higher I_{min} level, the more profit the firm can gain; this is due to the extra revenue obtained from the government is higher than the additional cost required for maintaining the extra I_{min}.

- For any fixed I_{min} level, the more flexibility allowed larger *Y*, which means firms can salvage the I_{min} amount earlier, the higher profit firms can gain; this is due to the extra flexibility given to firms that they can refresh their inventory in a shorter period hence reduce the average running cost of the proposed inventory system. However, the profit increases at different slopes with different Y values.

- The two dots, which on two different I_{min} level plot lines and at the same profit level, demonstrate the trade-off between the high flexibility for the firms and the low minimum inventory requirement for the government. If the government would pay less to the firms by requiring a smaller amount of minimum inventory, it must allow more flexibility (longer time before the expiration to salvage the pills) for the firms to obtain the same level of profitability.

4. Collaborative Projects

We have collaborated with two other CREATE projects. The bioharzard project led by Terence O'Sullivan was a useful resource for our project in providing scenario parameter settings for our experiments. Our expertise in supply chain derived from this research permitted us to provide consultation on the economic impact on supply chain disruptions in a project led by Adam Rose.

5. Research Products

Research Products (Please detail below)		**#**
5a	# of peer-reviewed journal reports published	4
5a	# of peer-reviewed journal reports accepted for publication	1
5a	# of non-peer reviewed publications and reports	4
5a	# of scholarly journal citations of published reports	16
5b	# of scholarly presentations (conferences, workshops, seminars)	9
5b	# of outreach presentations (non-technical groups, general public)	2
5c	# of products delivered to DHS, other Federal agencies, or State/Local	
5c	# of patents filed	
5c	# of patents issued	
5c	# of products in commercialization pipeline (products not yet to market)	
5c	# of products introduced to market	

Citations are from Google Scholar.

5.1. Publications and Reports

	Publications	**Ref**	**Not Ref**
1.	Shen, Z., Ordonez, F., Dessouky, M., "The Minimum Unmet Demand Stochastic Vehicle Routing Problem," accepted for publication, *Springer Series on Optimization and Its Applications*	x	
2.	Shen, Z., Dessouky, M., Ordonez, F., "The Stochastic Vehicle Routing Problem for Large-scale Emergencies," submitted for publication, *Networks*	x	
3.	Shen, Z., Ordóñez, F., Dessouky, M., "The Stochastic Vehicle Routing Problem for Minimum Unmet Demand," accepted for publication in *Springer Series on Optimization and its Applications*	x	
4.	Ordonez, F., Sungur, I., Dessouky, M., "A Robust Optimization Approach for the Capacitated Vehicle Routing Problem with Demand Uncertainty," *IIE Transactions*, 40, 509–523, 2008	x	
5.	Ordonez, F., Sungur, I., Dessouky, M., "A Priori Performance Measures for Arc-based Formulations of the Vehicle Routing Problem," *Transportation Research Record*, 2032, 53-62, 2007	x	

5.2. Presentations

<u>Conferences</u>

- Murali, P., Dessouky, M., Ordonez, F., "Capacitated Facility Location for Disbursement of Supplies in a Large-scale Emergency," *International Locational Decisions XI*, Santa Barbara, CA, June 2008

- Shen, Z., Ordonez, F., Dessouky, M., "Stochastic Routing for Large-Scale Emergencies," *National Meeting of INFORMS*, Seattle, WA, November 2007
- Shen, Z., Ordonez, F., Dessouky, M., "Models and Algorithms for Effective Emergency Supply Planning," *INFORMS*, Seattle, WA, November 2007
- Murali,P., Ordóñez, F., Dessouky, M., "Capacitated Facility Location for Disbursement of Supplies in a Large-scale Emergency," *INFORMS*, Seattle WA, November 2007

5.3. Models, Databases, and Software Tools and Products

A GIS based facility locator and router model and software tool have been developed and a supply chain model of the VMI has been developed.

6. Education and Outreach Products

Education and Outreach Initiatives	#
# of students supported (funded by CREATE)	3
# of students involved (funded by CREATE + any other programs)	4
# of students graduated	1
# of contacts with DHS, other Federal agencies, or State/Local (committees)	
# of existing courses modified with new material	
# of new courses developed	
# of new certificate programs developed	
# of new degree programs developed	

This project supported three PhD students: Zhihong Shen, Diego Prats, and. Yen-Ming Lee. Zhihong Shen successfully defended her dissertation and has joined Microsoft Corporation.