Healthcare Logistics Cost Optimization Using a Multi-criteria Inventory Classification

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Abstract

In this paper, a system dynamics model of a hospital logistics system is developed to evaluate different inventory management techniques. The paper introduces a multi-criteria inventory classification method that takes into account the criticality, cost, and usage value of items. Based on the model, extensive simulations were conducted to evaluate the cost of inventory management for items based on the criticality of need, service level assignments and consumption rates. The analysis presented provides useful guidelines for the health practitioners and decision makers how inventory management cost could be optimized using a classification system depending on the criticality of the items.

Keywords
Health care, logistics, criticality of medical items, system dynamics

1. Introduction
A distinctive feature of healthcare logistics is the use of a large number of different products that are ranged in between high-critical to low-critical items. The unavailability of critical items could lead to life threatening situations. This distinctive feature of healthcare logistics may require different management policies than those used for other industries logistics systems.

The ABC inventory classification method has been specifically proposed by researchers [1-3] to help hospitals logistics managers to categorize inventory items so that effective managerial policies and procedures can be implemented. The ABC approach [4] is based on the fact that a small fraction of items account for a high percentage of total dollar use, and that these items are classified as Class A and are given greater management attention. Whereas, the rest of the items are classified as Class B and Class C and are given moderate to low attention, respectively. The main limitation of applying the ABC approach in healthcare logistics is that some critical items that may demonstrate low usage value will not receive priority attention under this method.

In this paper, an alternative multi-criteria inventory classification method is introduced that takes into account the criticality, cost, and usage value of items. A system dynamics model of a hospital logistics system is developed to conduct extensive dynamic analysis to study the impact of using the multi-criteria inventory classification method on logistics cost reduction.

2. Research Methodology
This research makes use of system dynamics as the main medium of analysis. In particular, an integrated system dynamics framework for supply chain is used for analyzing and modeling the dynamic behavior of hospitals logistics systems. The framework has been successfully used for modeling and analyzing a number of supply chains, for example in the steel industry by Hafeez *et al.* [5], in the electronic industry by Berry and Naim [6], and in the

medical supplies industry by Evans *et al.* [7]. Mason-Jones has used system dynamics to model three echelon supply chain using efficient consumer response strategy [8].

3. The Case Study

Our case study organization was a children hospital from the private healthcare sector in the USA. The case hospital is a member of Premier –one of the biggest GPOs (group purchasing organizations) in the USA. An essential function of a GPO is to provide its member hospitals with an aggregate buying power in order to obtain discount from manufacturers and distributors. Figure 1 shows the case hospital supply chain which includes: the case hospital itself, its primary and secondary distributors, and product manufacturers. The hospital orders most of its supplies from one primary distributor and three secondary distributors. In turn, these distributors order their supplies from manufacturers. The remaining hospital supplies are ordered directly from product manufacturers.
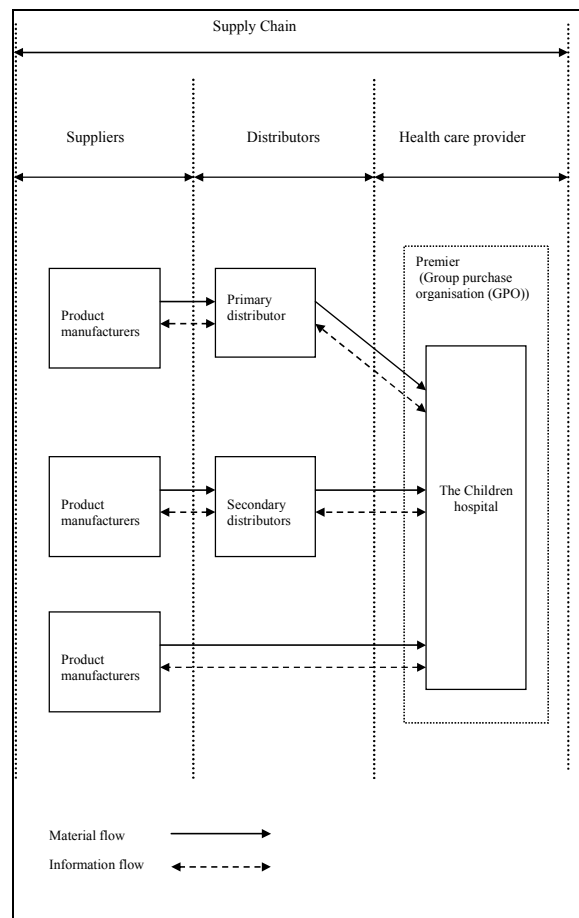

Figure 1: The overall material and information flow in the case hospital supply chain

4. Inventory Management

The inventory control policy proposed to be studied for the case hospital is referred to as CR(IOBPCS) -continuous replenishment (Inventory and Order Based Production Control System). The main concept of CR, as its name implies, is that the order rate is adjusted continuously based on actual or forecasted demand. However, in practice, the CR decision rule may take various forms depending on the relevant industry characteristics. A number of recent studies have proposed analytical models to represent the CR decision rule, see for example [9-14].

However, we propose to employ the well-studied inventory and order based production control system (IOBPCS) as a CR specific decision rule. Coyle [15] suggests that the IOBPCS represent much of the industrial practice associated with manual production control systems. Although the IOBPCS model was developed initially in terms of smoothing factory orders, it can be readily modified to represent other links in the supply chain [16]. In the IOBPCS model, the ordering rule is based upon forecast demand and the difference between a fixed target level of inventory and the actual level [5, 17].

5. Computer Simulation Model

A stock-flow diagram, illustrated in Figure 2, was developed for the case hospital logistics system, representing CR(IOBPCS) inventory control approach. The corresponding computer simulation model for the stock-flow diagram in Figure 2 was developed using the *ithink* Analyst Software (one of the industry standard system dynamics software). Table 1 gives details about the CR(IOBPCS) algorithm and describes how the inventory control decision of (How often to review? When to order? and How much to order?) is determined. It also provides a list of all the variables that are used to determine this decision. It has been found [18] that design parameters $(Ta/Tp)=1$ and $(Ti/Tp)=3$ (as described in Table 1) provide optimum response for the CR(IOBPCS) model which is impacted by the pipeline delays.
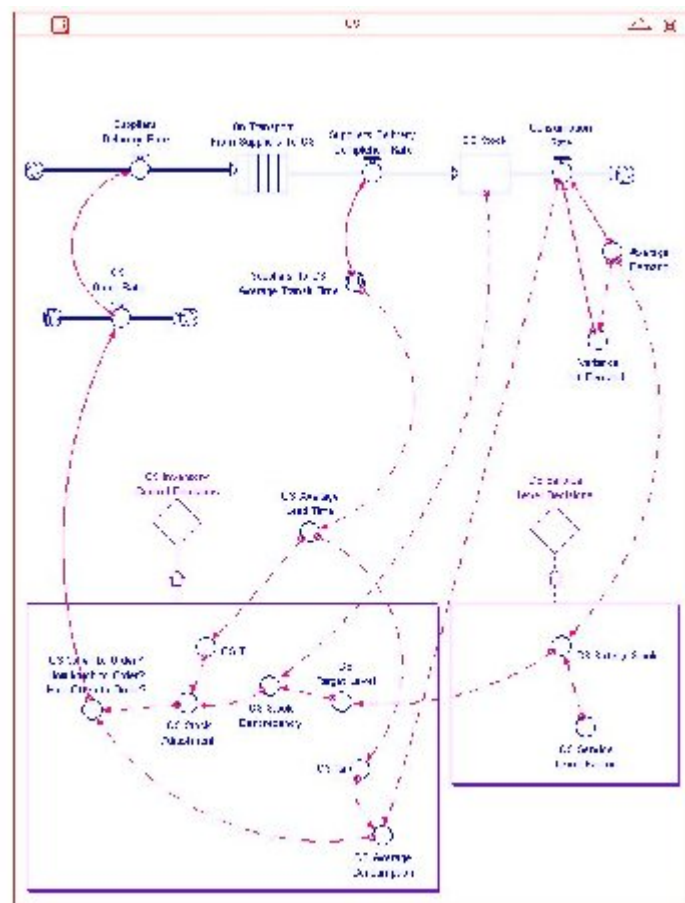

Figure 2: The stock-flow diagram of the case hospital logistics system for the CR(IOBPCS) inventory control approach (note: CS in the diagram refers to the case hospital central supply)

The computer simulation model (in Figure 2) was then subjected to extensive dynamic analysis to represent the relative time behavior. It was run for different combinations of item unit cost, average demand, and standard deviation of demand to represent a wide range of different items used by the hospital. In the simulation runs, it has been assumed that all items are treated the same in terms of service level delivered (i.e. assumed that 100% service

level (k=1) is to be delivered for each item irrespective of its criticality level). The simulation results illustrated that when using the CR(IOBPCS) inventory control approach, the inventory control decisions are linear, generating continuous-time order flows.

Table 1: Explanation of the CR(IOBPCS) inventory control approach

Inventory control approach	CR(IOBPCS)
Description of the approach	Order rate is adjusted continuously at each period t and is equal to the sum of forecasted demand and a fraction $(1/T_i)$ of the stock discrepancy.
Inventory control decision: *How Often to Review?* *When to Order?* *How Much to Order?*	At each period t At each period t Order quantity at time $t = O_t$, where $$O_t = \text{AVCON}_t^{T_a} + \frac{1}{T_i}(\text{TL} - \text{AL}_t)$$ $$\text{TL} = kD$$ (T_a / T_p) and (T_i / T_p) are design parameters which are chosen to give acceptable system performance.
Variables used in the decision rule	$\text{AVCON}_t^{T_a}$: average consumption at time t which is the demand forecast using simple exponential smoothing with parameter T_a (items per unit time) T_a : demand averaging time constant. TL : target level (items) (which is considered as safety stock) D : average demand (number of items per unit time) k = service level factor AL_t : actual level at time t (items) T_i : inverse of inventory based production control law gain. T_p: average lead time (units of time)

Source: [17]

6. Inventory Classification

Inventory classification has been used for hospital logistics [19-21] as a simple yet very effective technique for stratifying individual items into logical groupings for management where "generic" control policies are set for each group. Under such policies, common logistics decisions (such as service level decisions) are applied to each item in a group.

In this research work, it is proposed to incorporate inventory classification into the CR(IOBPCS) simulation model. We suggest to classify items using a multi-criteria inventory classification method (shown in Figure 3) that takes into account the criticality, cost, and usage value of items and study the impact of its use on logistics cost reduction. As shown in Figure 3, one dimension of the matrix classifies items in terms of criticality as high, medium and low according to the following criteria:

- High-critical items are either essential for the work carried out and/or have no immediate alternative.
- Medium-critical items are important for the work, but may have acceptable alternatives or other sizes may be used in the event of stock-out.
- Low-critical items are unlikely to affect the well being of patients other than causing minor inconveniences when out of stock.

The other dimension of the matrix shown in Figure 3 classifies items according to the ABC analysis classification in terms of annual dollar usage as A item, B item and C item. The procedure for conducting an ABC analysis classification is described at length elsewhere [1-3].

Each group of items in the multi-criteria inventory classification matrix is assigned an appropriate % service level and a service level factor (k) as shown in Figure 3. The new specified service level factor (k) was then used to run the computer simulation model in Figure 2 for different combinations of item unit cost, average demand, and standard deviation of demand to represent a wide range of different items used by the hospital. The resulting simulation outputs were used to study how incorporating inventory classification into the model affects average stock, number of orders, and inventory cost.

		Criticality classification		
		High criticality	Medium criticality	Low criticality
ABC Analysis Classification	A item	100 % service level (k = 1)	90 % service level (k = 0.9)	80 % service level (k = 0.8)
	B item	100 % service level (k = 1)	100 % service level (k = 1)	80 % service level (k = 0.8)
	C item	100 % service level (k = 1)	100 % service level (k = 1)	90 % service level (k = 0.9)

Figure 3: The proposed multi-criteria inventory classification matrix

7. Simulation Results

Figure 4 (a) & (b), Figure 5 (a) & (b), and Figure 6 (a) & (b) show, respectively, the % decrease in average stock, the % increase in number of orders, and the % savings in inventory cost when the value of the service level factor (k) changes from 1 to 0.9 and from 1 to 0.8. As shown in Figure 5 (a) & (b), changing the value of the service level factor (k) does not affect the number of orders (i.e. the % change in number of orders is zero). However, changing the value of the service level factor (k) causes a change in average stock. This is because average stock depends on the value of target level which in turn depends on the value of k (see Table 1), such that the smaller the value of k the smaller the value of target level and hence the smaller the value of average stock. Therefore, as shown in Figure 4 (a) & (b), the % decrease in average stock when k changes from 1 to 0.8 is higher than when k changes from 1 to 0.9. Consequently, as shown in Figure 6 (a) & (b), the % savings in inventory cost is caused by the % decrease in average stock, such that the higher the % decrease in average stock the higher the % savings in inventory cost. Therefore, the % savings in inventory cost when k changes from 1 to 0.8 is relatively more than when k changes from 1 to 0.9.

(a) % Decrease in average stock (k change from 1 to 0.9)   (b) % Decrease in average stock (k change from 1 to 0.8)
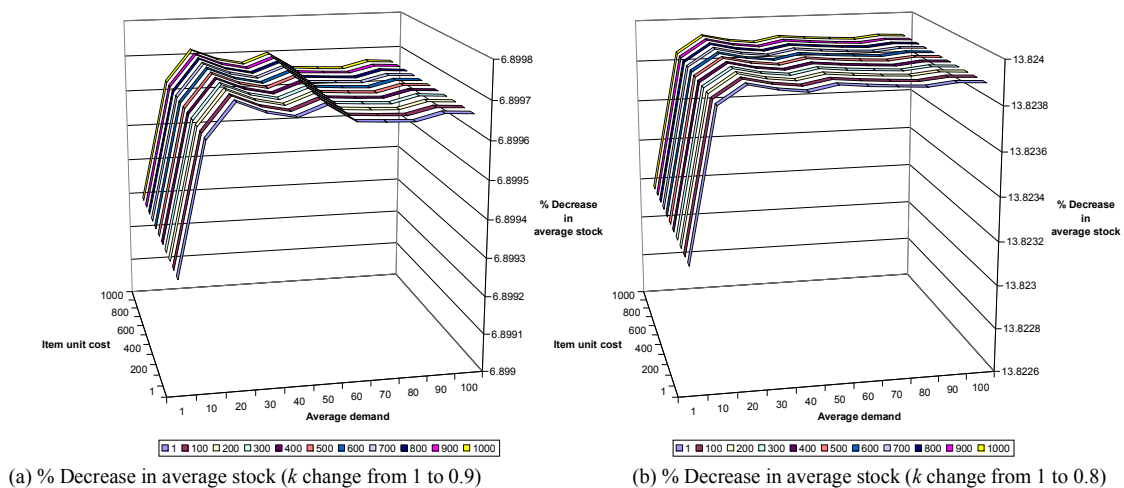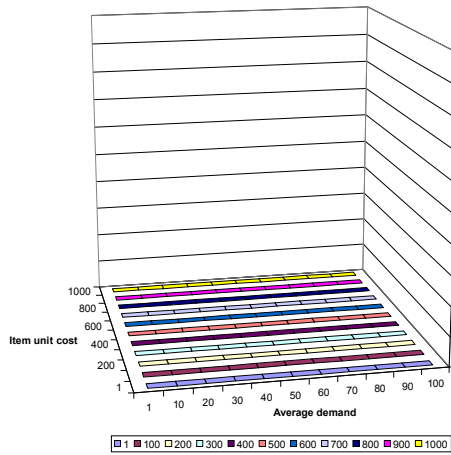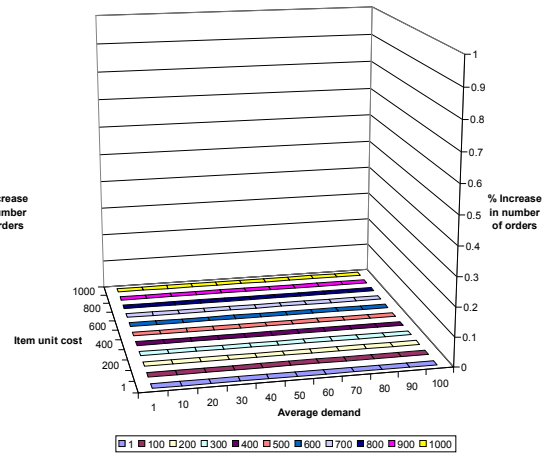
Figure 4: The % decrease in average stock when the value of the service level factor (k) changes from 1 to 0.9 and from 1 to 0.8
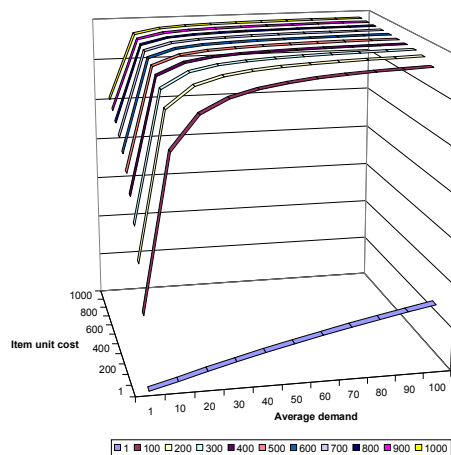
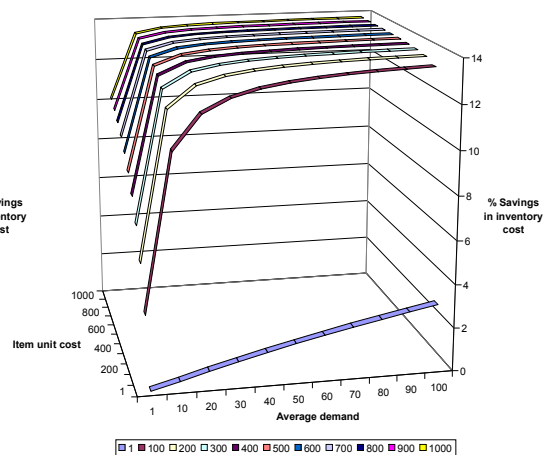(a) % Increase in number of orders (*k* change from 1 to 0.9)

(b) % Increase in number of orders (*k* change from 1 to 0.8)

Figure 5: The % increase in number of orders when the value of the service level factor (k) changes from 1 to 0.9 and from 1 to 0.8

(a) % Savings in inventory cost (*k* change from 1 to 0.9)

(b) % Savings in inventory cost (*k* change from 1 to 0.8)

Figure 6: The % savings in inventory cost when the value of the service level factor (k) changes from 1 to 0.9 and from 1 to 0.8

8. Conclusions

Hospital management has always been concerned with optimizing logistics cost in a healthcare supply chain operation. This work has rigorously tested a multi-criteria inventory classification method that takes into account the criticality, cost, and usage value of items for optimizing overall inventory cost while maintaining the required patient care/service level. It is concluded that assigning a different % service level to items according to their criticality, usage, and value not only can reduce inventory cost, however, ensure the availability of items that are critical for human life saving. The results of this study provide guidelines to hospital logistics managers to devise appropriate inventory control policies.

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