Developing Inventory Management in Hospital

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Abstract— **Single inventory policy has been applied to entire types of drugs in hospitals, despite several different drug and demand characteristics. Shortages regularly occur, which may affect patients' lives, especially when vital drugs are being administered to them. However, hospitals cannot store a large amount of every drug because of limited space and budget. The objective of this study was to develop a hospital inventory management system to minimise the total inventory costs, while maintaining patient safety levels. The study is concerned only with the medicines that have a high consumption value and took place in a large public hospital in Thailand. The most suitable policies are proposed for each drug category with the best performance obtained. The historical demand is classified by drug characteristics, consumption value and clinical importance, as well as the demand characteristics. We applied it and compared it with the current inventory policy (Min/Max), and inventory policies from previous studies, in order to investigate the most suitable inventory policy for each drug category and demand characteristic. The study found that a single inventory management system cannot be effectively applied for all medicines. It is because there are also categories of medicines characterised by their value and clinical importance. This is called the ABC/VEN classification. The inventory management in hospitals should be fitted to drug categories and demand characteristics, which are quite unique in the healthcare supply chain and are different from those applied to general manufacturing.**

Keywords— *Inventory management, Hospital, Drug, Clinical importance*

1. Introduction

Healthcare expenditure is generally concentrated on the use of drugs because they are important products in curative care. Hospitals have been controlling the costs of drugs, which are stocked excessively, to maintain high service levels as a requirement; especially in developing countries [1, 2]. Holding high drug stocks involves extra costs, such as those for replacing expired and deteriorated drugs. Consequently, hospitals can ineffectively

control annual expenditure [3, 4] and lose opportunities to service patients.

In this case study of a large government hospital in Thailand, one single inventory policy is applied to all drugs in the hospital, without the consideration of demand patterns.

The disadvantage of using one policy for all drugs in a hospital is that inventory problems occur, such as drug shortages, which then directly affect patient service levels, especially when using vital drugs. One common-used policy is called the Min/Max policy. The logic flow of this policy begins when the drug orders from each ward of a hospital are placed with the central drug department every morning. The daily transactions of drug orders are collected, with the order quantity based on the experience of the pharmacists. The drug usage is collated every month, and is called the monthly sale (Msale). When the levels of drug inventory on hand is less than or equal to 70–80% of Msale, the pharmacists in the drug inventory departments will place a purchase request (PR) to the procurement department; the suppliers will receive a purchase order (PO) from the procurement department the next day and the order quantity is the number of drugs that raise the inventory on hand up to 100–150% of Msale [5].

Here, in this study, we developed a drug inventory policy suitable for each drug category, rather than applying a single Min/Max policy for all categories. We proposed a planning system, consisting of: when to order, how much to order and how to handle the various types of drugs. Establishing a suitable policy for each demand type is the way to manage drug inventories in a hospital. A suitable inventory policy should reduce the total inventory cost while still maintaining the service levels to patients.

This study is concerned only with the medicines in the outpatient department (OPD) of a large public hospital in Thailand, retrieved from the records available on the Hospital Information System (HIS) for the period 2009-2012. Only high consumption value drugs (which are about 70% of total annual drug value) are taken into account.

Selected inventory models are tested for each drug category and demand characteristic. Then, a suitable inventory policy for each drug type was developed.

2. Research Framework

The research processes began with collecting data using interviews and surveys at the site. Then we classified the drugs using the ABC/VEN analysis. ABC relates to the consumption value and VEN relates to clinical importance. In this study, we focussed on drugs with a high consumption value (A class). The current policy and inventory policies from previous studies were compared, in order to find a suitable policy for each drug category. Then, a suitable inventory policy for each drug characteristic was proposed. These processes are summarised in Figure 1.
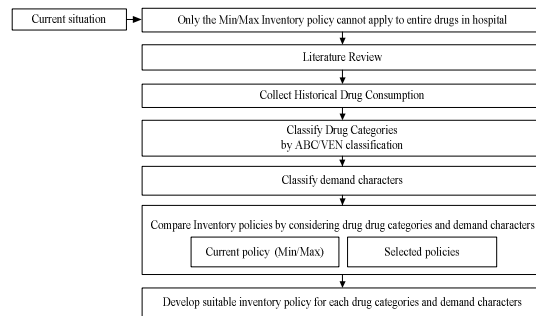

Figure 1   Research Processes

From the 1,951 drug SKUs (Stock keeping units) in the central drug store in fiscal year 2012, the A category, which account for 70% of the total expenditure, was selected for this study. By considering the VEN analysis, the A category of drugs can be divided into the following items: drugs with high consumption value and vital clinical importance (AV); drugs with high consumption value and essential clinical importance (AE); and drugs with high consumption value and non-essential clinical importance (AN). Then the historical demands of each drug category were analysed. The current Min/Max inventory policy in the hospital was compared to the inventory policies selected from the previous studies.

3. Literature Review

3.1 Inventory Management

Inventory management is a trade-off between the costs of keeping an inventory versus the benefits of holding it. High inventory levels result in increased carrying costs but lower the possibility of lost sales because of stock-outs and slowing production, which can result from inadequate stocking [5, 7, 10]

Lead time (LT) is the time elapsed between ordering items and receiving them from suppliers. The reorder point (ROP) is the level that stock reaches when a new order must be placed [6, 8, 11] Safety stock or buffer stock is a quantity of a drug inventory held as a reserve to safeguard against variations in demand and LT for procurement. Safety stock is one factor to consider in establishing the ROP. Another factor to be considered, when replenishing drug supplies, is service levels, meaning the ratio between the number of available products for customers and the total product demand. The order quantity model, which is widely used, is the economic ordering quantity (EOQ), which is calculated from the holding cost and the ordering cost. It is the quantity of materials to be ordered and minimises the total costs of carrying inventories and ordering costs [9, 12].

To manage inventory, the inventory classification must be taken into account. The reason for classifying inventory is to reduce the need to control a plentiful item in the inventory. If all items have equally strict control, time and costs are unnecessarily wasted. Classification can help to focus on highly-prioritised items [7, 8, 12].

3.2 Drug Category

Pareto ABC analysis is a method used for supporting stock management, which has stock volumes in the hundreds or more. The objective of this method is to reduce complexity and increase the efficiency of stock management. All products in stock are classified by the total value of sold product [8, 10]. In this study, the annual consumption value of the drugs in an OPD, in the fiscal year 2012, was arranged from low to high values and then divided into three groups: A, B and C.

Group A items represent high usage and account for 70% of usage value; the total quantity is 10% of line items.

Group B items represent average usage and account for 20% of usage value; the total quantity is 20% of line items.

Finally, group C items represent low usage and account for 10% of the value expended; the total quantity is 70% of line items [8, 10, 12, 14].

VEN (vital, essential, non-essential) classification is used to determine the drug's clinical importance. Drug administration in hospitals is complex and

13

Int. J Sup. Chain. Mgt   Vol. 4, No. 2, June 2015

different from other general industries. The effects of drug shortages have an impact on human lives. Therefore, ABC classification is not adequate in supporting drug inventory management.

It was mentioned that VEN is another useful tool for defining which items on the inventory list must be held in stock [14, 15]. In the VEN system, drug items are classified by pharmacists in a hospital once a year to prioritise procurement. It was stated that the VEN system also helps pharmacists to determine which items should be kept in stock and which can be ordered when needed. The basic criteria for classifying drugs by VEN analysis are shown below [5, 15, 17].

• Category V: vital drugs are the most important drugs and needed for clinical therapy; such as vaccines and serums.

• Category E: essential drugs are moderately important drugs used to cure less severe diseases than V items.

• Category N: non-essential drugs are the least important drugs and are seldom used in the treatment of illness.

In previous studies, only the ABC classification is taken into account. The level of clinical important was neglected. When we consider the VEN dimension in the ABC classes, nine categories from ABC/VEN matrix can be listed. These are AV, AE, AN, BV, BE, BN, CV, CE and CN which are shown in Table 1.

Table 1. ABC/VEN matrix

		ABC category		
		High consumption value (A)	**Medium consumption value (B)**	**Low consumption value (C)**
VEN category	**Vital (V)**	AV	BV	CV
	Essential (E)	AE	BE	CE
	Non-essential (N)	AN	BN	CN

*Only AV, AE and AN are considered in this study.

3.3 Demand Characters and Inventory Policy

To manage inventory, first of all we need to define the demand patterns [7, 8, 12, 17]. Most of the studies worked with the assumption that the distribution of drug demand and LT are normal [11, 17]. However, some drug demands are non-normal distributions, which can be tested by Kolmogorov-Smirnov [6]. Some drug demands have trends [10, 17], the type of trend is tested by a run test and regression analysis considering the R-square (R^2) [6]. Some drug demands are lumpy but some are

static [7, 9, 12]. The Peterson–Silver rule is used to determine the variability of data by value (V) [18]. If V is less than 0.25, the demand is static. Otherwise, the demand is lumpy.

The demand characters in the previous studies can be summarised as 1) Normal distribution with no trend but static demand; 2) Normal distribution with no trend but lumpy demand; 3) Normal distribution with trend demand; and 4) Non-normal distribution demand.

(s,S) policy is applied for normal distribution with no trend demand [5, 6, 11].

where
$$s = \frac{L \cdot \mu_{week} + z\sqrt{nL} \cdot \sigma_{week}}{\frac{\mu_{week}}{n}} \qquad (1)$$

$$S = M \frac{\mu_{week}}{n} + k + s \qquad (2)$$

by which
- s = reorder point (unit)
- μ = mean of demands (unit)
- L = lead time (day)
- z = the standardized random variable
- n = service days in a week (day)
- σ = standard variation
- S = maximum level (unit)
- M = storage day (day)
- k = special demand that known before (unit)

They also applied (s,Q) policy for normal distribution with static demand [5, 6, 11].

where
$$s = \mu_{day}(L+1) \qquad (3)$$

$$Q = max\left\{\left\lceil\frac{\mu N + S - I}{y}\right\rceil, mo\right\} \qquad (4)$$

by which
- s = reorder point (unit)
- μ = mean of demands (unit)
- L = lead time (day)
- Q = Order quantity (unit)
- N = storage day (day)
- S = maximum level (unit)
- I = inventory level at reorder point (unit)
- y = the unit of boxes (unit)
- mo = minimum order quantity (unit)

Moreover, (s,Q) policy is applied for normal distribution with lumpy demand [5, 6, 11].

where
$$s = \frac{L \cdot \mu_{week} + z\sqrt{nL} \cdot \sigma_{week}}{n} \qquad (5)$$

$$Q = max\left\{\left\lceil\frac{\mu N + S - I}{y}\right\rceil, mo\right\} \qquad (6)$$

by which
- s = reorder point (unit)
- L = lead time (day)
- μ = mean of demands (unit)
- z = the standardized random variable
- n = service days in a week (day)
- σ = standard variation
- Q = Order quantity (unit)
- N = storage day (day)
- S = maximum level (unit)

14

Int. J Sup. Chain. Mgt   Vol. 4, No. 2, June 2015

I = inventory level at reorder point (unit)

y = the unit of boxes (unit)

mo = minimum order quantity (unit)

(s,Q) policy is applied based on EOQ to normal distribution with no trend but static demand [7, 11, 13, 17].

where

$$s = \mu_{day}(L) \qquad (7)$$

$$Q = \sqrt{\frac{2AD}{h}} \qquad (8)$$

by which

s = reorder point (unit)

μ = mean of demands (unit)

L = lead time (day)

Q = Order quantity (unit)

A = Ordering cost per time (baht per time)

D = Annual drug demand (unit per year)

h = holding cost (baht)

(s,Q) is also applied based on simple linear regression for normal distribution with trend demand [5, 10, 12].

where

$$s = \int_{t=c}^{t=d} f(d_t)dt + z\sqrt{L}\,\sigma_{day} \qquad (9)$$

$$Q = \int_{t=a}^{t=b} f(d_t)dt + k \qquad (10)$$

by which

s = reorder point

z = the standardized random variable

L = lead time (day)

σ = standard variation

μ = mean of demands (unit)

c = date of ordering drug

d = date of receiving drug

$d-c$ = lead time

Q = Order quantity (unit)

k = special demand that known before (unit)

a = date begin to storage drug

b = date finish to storage drug

$b-a$ = number of day to storage drug (M)

On the other hand, dynamic lot sizing is applied to normal distribution with no trend but lumpy demand [10].

where s = order every month (Fixed ordering time)

Q = Average weekly demand * 4

by which the reorder point (s) are fixed by hospital policy and order quantity (Q) is ordered for monthly demand based on the demand of previous month, which is calculated every month.

This dynamic lot sizing is also applied for the non-normal distribution demand [5, 10].

These are all summarised in Table 2.

Table 2. Inventory policy from previous studies for particular demand characteristics

Demand character	Inventory policy	Reference
1. Normal distribution with no trend but static demand	**(s,S) policy for normal distribution demand:** $$s = \frac{L \cdot \mu_{week} + z\sqrt{nL} \cdot \sigma_{week}}{}$$ $$S = M\frac{\overline{\mu_{week}}}{n} + \overline{k} + s$$	[5, 6, 11]
	(s,Q) policy for static demand and pack size ordering: $s = \mu_{day}(L+1)$ $Q = max\left\{\left\lceil\frac{\mu N + S - I}{y}\right\rceil, mo\right\}$	[5, 6, 11]
	(s,Q) policy based on EOQ: $s = \mu_{day}(L)$ $Q = \sqrt{\frac{2AD}{h}}$	[7, 11, 13, 17]
2. Normal distribution with no trend but lumpy demand	**(s,S) policy for normal distribution demand:** $$s = \frac{L \cdot \mu_{week} + z\sqrt{nL} \cdot \sigma_{week}}{}$$ $$S = M\frac{\overline{\mu_{week}}}{n} + \overline{k} + s$$	[5, 6, 11]
	(s,Q) policy for lumpy demand and pack size ordering: $s = \frac{L \cdot \mu_{week} + z\sqrt{nL} \cdot \sigma_{week}}{}$ $Q = max\left\{\left\lceil\frac{\mu N + S - I}{y}\right\rceil, mo\right\}$	
	dynamic lot sizing s = order every month (Fixed ordering time) Q = Average weekly demand * 4	[10]
3. Normal distribution with trend demand	**(s,Q) based on simple linear regression:** $s = \int_{t=c}^{t=d} f(d_t)dt + z\sqrt{L}\sigma_{day}$ $Q = \int_{t=a}^{t=b} f(d_t)dt + k$	[5]
4. Non-normal distribution demand	**Dynamic lot sizing:** s = order every month (Fixed ordering time) Q = Average weekly demand * 4	[5, 10]

4. Case study and data collection

4.1 Input Data

From interviewing pharmacists in the pharmacy department and central drug inventory of a large public hospitals, located in Bangkok, Thailand, and the previous studies [6], it was found that only the drug ordering policy, called Min/Max, is applied to all drugs. This causes inventory problems – both shortages and overstocking of some drugs. Therefore, if drug inventories can be controlled at a suitable quantity with clinical importance concerns,

15

Int. J Sup. Chain. Mgt   Vol. 4, No. 2, June 2015

patients should receive their required drugs at the right times and hospitals can manage expenditure more effectively, while achieving patient safety levels.

For this reason, the current inventory policy was investigated and tested with the other inventory policies in the previous section. The data concerns only the medicines from the OPD of a large public hospital in Thailand, retrieved from the records available on the hospital information system (HIS) for the 2009–2012. Only drugs with a high consumption value – about 70% of total annual drug value – are focused on, the purpose being to reduce expenditures and increase the effectiveness of drug utilisation. Medical devices and other consumables are not included.

4.2 Drug Categories and Demand Characters

Because this study focus on the drugs that demand large expenditure from the hospital, drug demand of the OPD for the fiscal year 2012 were classified by ABC/VEN analysis according to both value consumption and vital criteria. Starting with value consumption of 1,951 items, the first 70% (208 items) were classified into the A category, the next 20% (327 items) into the B category and the next 10% (1,416 items) into the C category.

Further, to focus on each area of clinical importance (VEN), the summary results of analysis of A category drugs can be divided into three subcategories: drugs with a high consumption value and vital clinical importance (AV); drugs with a high consumption value and essential clinical importance (AE); and drugs with a high consumption value and non-essential clinical importance (AN).

The historical consumption data of A category drugs, (high consumption value) in the record available on the hospital information system (HIS) database, between January 2009 through to December 2012, was analysed by boxplot to remove outliers; a run test was used to determine the randomness or trend data; a Kolmogorov–Smirnov test was used to establish normality; and the Peterson–Silver rule was used to test variability. The data were analysed using Microsoft Excel version 2010. The examples of historical drug consumption in 2009-2012 are shown in Figure 2-3.
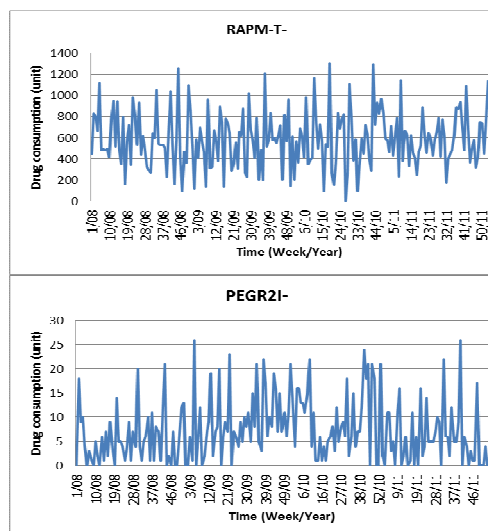
Figure 2. (Up) Example of historical drug consumption which has normal distribution with no trend but static demand; (Down) Example of historical drug consumption which has normal distribution with no trend but lumpy demand
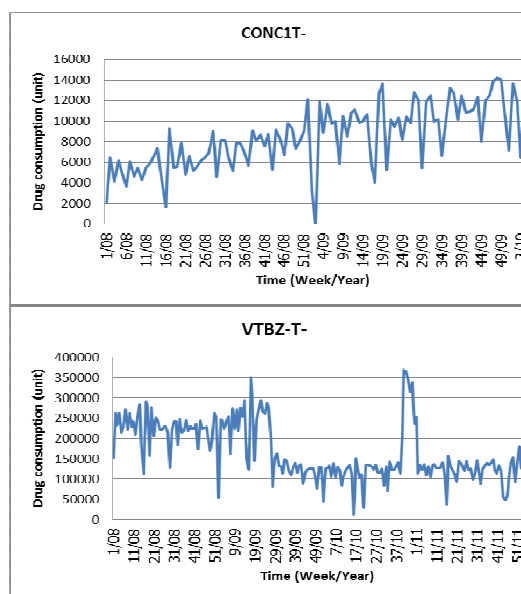
Figure 3. (Up) Example of historical drug consumption which has normal distribution with trend demand; (Down) Example of historical drug consumption which has non-normal distribution demand

Each drug's data is analysed and mapped to the four groups of demand characters: 1) Normal distribution with no trend but static demand; 2) Normal distribution with no trend but lumpy demand; 3) Normal distribution with trend demand; and 4) Non-normal distribution demand. It is found that drugs in the AV category have the

16

Int. J Sup. Chain. Mgt   Vol. 4, No. 2, June 2015

characteristics of groups one, two and four. Drugs in the AE category have the characteristics of groups one, two, three and four. Drug in the AN category have the characteristics of groups one and four. These are summarised in Table 3.

Table 3. Drug category and its group of demand characters

| Category | Drug demand characters | | | |
	Group 1 Normal distribution with no trend but static demand	Group2 Normal distribution with no trend but lumpy demand	Group3 Normal distribution with trend demand	Group4 Non-normal distribution demand
AV	✓	✓	N/A	✓
AE	✓	✓	✓	✓
AN	✓	N/A	N/A	✓

By considering the potential inventory policies for each demand characteristic (stated in Table 2), the data of each group in each category was tested. This was also compared with the current Min/Max policy. These are summarised in Table 4-6.

Table 4. Potential suitable inventories' policies for each demand characteristic of the AV category

| Drug demand characters | | |
Group 1 Normal distribution with no trend but static demand	Group2 Normal distribution with no trend but lumpy demand	Group4 Non-normal distribution demand
Min/Max	Min/Max	Min/Max
(s,S) policy for normal distribution demand	(s,S) policy for normal distribution demand	dynamic lot sizing
(s,Q) policy for static demand and pack size ordering	(s,Q) policy for lumpy demand and pack size ordering	-
(s,Q) policy based on EOQ	dynamic lot sizing	-

Table 5. Potential suitable inventories' policies for each demand characteristic of the AE category

| Drug demand characters | | | |
Group 1 Normal distribution with no trend but static demand	Group2 Normal distribution with no trend but lumpy demand	Group3 Normal distribution with trend demand	Group4 Non-normal distribution demand
Min/Max	Min/Max	Min/Max	Min/Max
(s,S) policy for normal distribution demand	(s,S) policy for normal distribution demand	(s,Q) based on simple linear regression	dynamic lot sizing
(s,Q) policy for static demand and pack size ordering	(s,Q) policy for lumpy demand and pack size ordering	-	-
(s,Q) policy based on EOQ	dynamic lot sizing	-	-

Table 6. Potential suitable inventories policies for each demand characteristic of the AN category

| Drug demand characters | |
Group 1 Normal distribution with no trend but static demand	Group4 Non-normal distribution demand
Min/Max	Min/Max
(s,S) policy for normal distribution demand	dynamic lot sizing
(s,Q) policy for static demand and pack size ordering	-
(s,Q) policy based on EOQ	-

4.3 Drug Performance Measurement

The study of inventory management in hospitals [4-6] shows that there are several key performance indexes (KPIs) to measure the performance in hospital inventories. Average inventory level, shortage days, number of shortages and length of shortage are seen to be frequently used as KPIs. Typically, average inventory level is of the highest concern and commonly converted to inventory cost.

However, vital drugs (V category) are different from essential and non-essential products since they have a very high health impact and patients take them to save lives. The inventory performance cannot consider only the typical lowest inventory cost or stock level.

Here we applied a pairwise ranking technique to identify the most important performance for the AV drugs. We asked the experts, who are specialists in the field of healthcare logistics, to compare the key performance indicator (KPI) priority.

First of all, each box in the matrix represents the intersection of KPIs (Key Performance Indexes) of inventory performances in the previous studies. There are average inventory level, shortage days, number of shortages and length of shortage. Then, the expert ranks each pair by indicating the more important KPIs in the appropriate box. Repeat this process until the matrix is filled as shown in Table 7.

Table 7. Result of the pairwise ranking for high consumption and vital drug category (AV category)

KPIs	Average inventory level	Shortage days	Number of shortages	Length of shortage
Average inventory level		Shortage days	Number of shortages	Length of shortage
Shortage days			Number of shortages	Shortage days
Number of shortages				Number of shortages
Length of shortage				

17

Int. J Sup. Chain. Mgt   Vol. 4, No. 2, June 2015

Then we listed the number of each alternative appears in the matrix and ranked them as shown in Table 8.

Table 8. Performance Ranking

Alternative (KPIs)	Number of shortages	Shortage days	Length of shortage	Average inventory level
Count	3	2	1	0
Rank	1st	2nd	3rd	4th

According to the pairwise ranking results in Table 8, the most important KPI factors for the drug category AV is the number of drug shortages. The suitable policy for the vital drugs must, thererfore, consider the minimum number of shortages; whereas, the typical inventory cost KPIs are applied to AE and AN drugs.

5. Results and Analysis

All drug items were tested with all potential drug inventory policies listed in Table 4-6. The most suitable policy for each demand characteristic for each drug category are summarised in Table 9.

Table 9. Suitable inventory polices for each demand character of each drug category

| Drug category	Group	Demand characters	Suitable policy	Pairwise ranking KPI
AV (drugs with high consumption value and vital)	1	Normal distribution with no trend but static demand	(s,S) for normal distribution demand	Minimum number of shortages
	2	Normal distribution with no trend but lumpy demand	(s,Q) for pack size ordering	
	*4	Non-normal distribution demand	Dynamic lot sizing	
AE (drugs with high consumption value and essential)	*1	Normal distribution with no trend but static demand	Min/Max	Minimum total inventory cost
	2	Normal distribution with no trend but lumpy demand	Dynamic lot sizing	
	3	Normal distribution with trend demand	(s,Q) based on simple linear regression	
	4	Non-normal distribution demand	Dynamic lot sizing	
AN (drugs with high consumption value and non-essential)	*1	Normal distribution with no trend but static demand	Min/Max	Minimum total inventory cost
	*4	Non-normal distribution demand		

* = Major group of each drug category

In the AV category, the results show that for the group 1-normal distribution with no trend but static demand, the (s,S) for normal distribution demand has the number of shortages as 20,962.30, compared to the 123,134.83 number of shortages from the Min/Max policy. For the group 2-normal distribution with no trend but lumpy demand, the (s,Q) for pack size ordering has 40.00 number of shortages whereas the Min/Max policy gives 1,763.49 number of shortages. For the group 4-non-normal distribution demand, the dynamic lot sizing has the number of shortages as 246.00, compared to 177,790.61 number of shortages from the Min/Max policy. The results are shown in Figure 4.
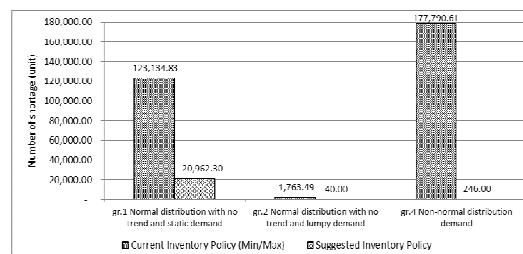
Figure 4. Number of shortages comparison between current inventory policy (Min/Max) and suggested inventory policies of drugs with high consumption value and deemed vital (AV category)
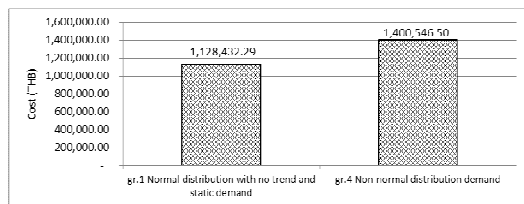
In the AE category, the results show that for the group 1-normal distribution with no trend but static demand, the Min/Max policy has a total inventory cost of THB 98,049,370.75, and so the Min/Max policy is the suggested inventory policy for this group. For the group 2-normal distribution with no trend but lumpy demand, the dynamic lot sizing has a total inventory cost of THB 26,678,874.58, whereas the Min/Max policy was THB 33,272,354.97.

For the group 3-normal distribution with trend demand, the (s,Q), based on simple linear regression, has a total inventory cost of THB 15,216,776.62, compared to THB 17,387,206.01 for the Min/Max policy. For the group 4-non-normal distribution demand, the dynamic lot sizing has a total inventory cost of THB 62,094,506.22, compared to THB 88,395,480.01 from the Min/Max policy. The results are shown in Figure 5.
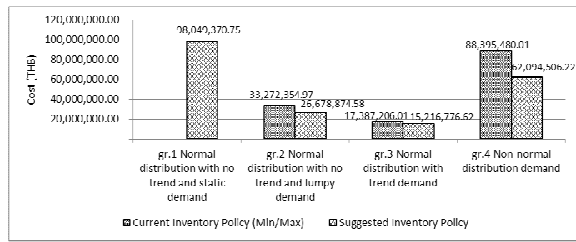
Figure 5. Cost comparison between current inventory policy (Min/Max) and suggested inventory policies of drugs with a high consumption value and deemed essential (AE category)

In the AN category, the results show that for the group 1-normal distribution with no trend but static demand, the Min/Max policy has a total inventory cost of THB 1,128,432.29. For the group 4-non-normal distribution demand, Min/Max policy has a total inventory cost of THB 1,400,546.50. Min/Max policy is the suggested inventory policy for all drugs in this group. The results are shown in Figure 6.

Figure 6. Cost comparison between current inventory policy (Min/Max) and suggested inventory policies of drugs with a high consumption value and deemed non-essential (AN category)

The results show that the suggested inventory policy can reduce the number of shortage in the AV category and reduce the total inventory cost for the AE and AN categories. In brief, the suggested inventory policies can reduce the number of shortages by as much as 92.98% and the total inventory cost by as much as 14.63%.

6. Discussion

The study show that using only ABC classification was not sufficient for drug inventory management, the clinical importance, which refers to VEN classification, must be taken into account. Nine metrics are proposed. The AV, AE and AN were selected in this study.

Further, it found 3 drug characteristics in the AV drug category. These are normal distribution with no trend but static demand; normal distribution with no trend but lumpy demand; and non-normal

distribution demand. The best policy fits are: the (s,S) for normal distribution demand for drugs with normal distribution with no trend but static demand; the (s,Q) for pack size ordering for drugs with normal distribution with no trend but lumpy demand; and the dynamic lot sizing for drugs with non-normal distribution demand.

For the AE drug category, there are 4 drug characteristics. These are normal distribution with no trend but static demand; normal distribution with no trend but lumpy demand; normal distribution with trend demand; and non-normal distribution demand. It can be seen that Min/Max fits drugs with normal distribution with no trend but static demand; whereas, dynamic lot sizing fits drugs with both normal distribution with no trend but lumpy demand and non-normal distribution demand. The (s,Q) based on simple linear regression fits drugs with normal distribution with trend demand.

For the AN drug category, there are 2 drug characteristics. These are normal distribution with no trend but static demand; and non-normal distribution demand. It can be seen that Min/Max fits both characteristics in this category.

Noticeably, most of the drugs with a high consumption value and vital clinical importance (AV drug category) are not steadily consumed; they are only used for severe cases. These drugs should be at minimal shortages as they are critical for life saving; their availability must be ensured even though the holding costs are high. Inventory ordering should be conducted at fixed intervals. Safety stock and ROP are calculated based on mean and variance from the normal distribution in order to ensure particular levels of stock.

Conversely, the drugs with high consumption value and essential clinical importance (AE drug category) are quite common and are prescribed steadily all through the year. Min/Max is the suitable inventory policy for most drugs in this category, which can minimise average inventory levels. Interestingly, for those drugs with the characteristics of normal distribution with trend, the inventory policy should be based on a simple regression model. The order quantity is calculated from the average demand plus the trend.

Most drugs with high consumption value and non-clinical importance (AN drug category) fit very well with the Min/Max inventory policy in order to minimise average inventory levels.

7. Conclusion

The study can be concluded that only single inventory policy cannot be applied to entire types of drugs in hospitals. The inventory management

19

Int. J Sup. Chain. Mgt   Vol. 4, No. 2, June 2015

policy should take into account both drug's value and clinical importance factors. Also, demand characteristics under each drug category must be concerned. By applying suggested inventory policy in this study, it is found that the number of shortages can be reduced as much as 92.98% and the total inventory cost can be reduced 14.63%.

Importantly, it must be noted that the drug inventory policy should be revised every year. This is due to the VEN classification being revised by hospital committees annually. Also, the ABC classes, which are revised every year according to annual demand and consumption, should also be taken into account.

Briefly, drugs are different from ordinary products on the market. They have levels of clinical impact. A Min/Max inventory policy is not appropriate to manage all drugs in the hospital, as at present, because drugs in the hospital have several demand characteristics, and the inventory policy should be customized to match specific drug demand characteristics.

For further research, it can be noted that the entire order policy presented in this paper can be considered as passive policy. The ordering is triggered by the ROP or a fixed period of time. On the other hand, if real-time demand and the stock levels can be shared with the hospital's supplier, active replenishment can be accurately undertaken. This is called a vendor managed inventory (VMI). Its application and implementation in hospitals is promising, yet challenging.

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References

[1] Inkpassakorn, V., "*Measures of medical supply manangement system reformation and the effect to regional and general hospital after economic crisis",* Health Policy and Planning, Vol.2, No.1, pp.5–16, 1999.

[2] Diarra, K., and Coulibaly, S., "*Financing of recurrent health costs in Mali",* Health Policy and Education, Vol.5, No.2, pp.126–128, 1990.

[3] Charupash, C., "*Simulation of drug classification by ABC analysis and economic order quantity model for drug inventory management in Khon Kaen hospital",* PhD thesis, Mahidol University, 2001.

[4] Kritchanchai, D., "*A Framework for Healthcare Supply Chain Improvement in Thailand*", Operation and Supply Chain Management, Vol.5, No.2, pp.103-113, 2012.

[5] Kritchanchai, D., Suwandechochai, R., "*Supply chain management in health sector in Thailand: a case study*", International Journal of Services, Economics and Management, Vol.2, No.2, pp.211-224, 2010.

[6] Suwandechochai, R., Muangpat, N., "*The analysis and improvement of appropriate model for medical inventory management: case study hospital",* Conference of Medical Data Standard Expo, Mahidol University, Thailand, pp.98-107, 2010.

[7] Donald J. Bowersox, David J. Closs., *Logistical management: The integrated supply chain process*, McGraw-Hill, 1996.

[8] Derek Waller. *Operations management: A supply chain approach*, Cengage Learning EMEA, 2003.

[9] Cecil C. Bozarth, Robert B. Handfield. *Introduction to operations and supply chain management,* Prentice Hall, 2006

[10] Heizer, Jay H., *Operations management*, Great Britain, Prentice Hall, 2001.

[11] John Coyle, Edward Bardi, John Langley, *Management of business logistics: A supply chain perspective*, Thomson Learning, 2002.

[12] Ronald Ballou, *Business logistics: supply chain management*, Prentice Hall, 2003.

[13] Kaur, J., Bapna, J.S., Bhoi, N., and Singh, O.P. "*Management of hospital pharmacy in private sector*", Journal of Health Management, Vol.8, No.1, pp.129–137, 2006.

[14] Vaz, F.S., Ferreira, A.M., Kulkarni, M.S., Motghare, D.D. "*A study of drug expenditure at a tertiary care hospital: an ABC-VED analysis",* Journal of Health Management, Vol.10, No.1, pp.119–127, 2008.

[15] Chungsiwapornpong, W., "*Survey of drug inventory control process and performance among hospital pharmacy departments in Thailand*", Master's thesis, Mahidol University, 2007.

[16] Thawani, V.R., Turankar, A.V., Sontakke, S.D., Pimpalkhute, S.V., Dakhale, G.N., Jaiswal, K.S., Gharpure, K. J., Dharmadhikari, S. D., "*Research paper – economic analysis of drug expenditure in government medical college hospital, Nagpur*", Indian Journal of Pharmacology, Vol.36, No.1, pp.15–19, 2004.

[17] Suksrisomboon, C., "*The development of an inventory management system for the Royal Thai Airforce*", Master's thesis, Chulalongkorn Univerisity, 2007.

[18] Silver, E.A., Pyke, D.F. and Peterson, R., *Inventory management and production planning and scheduling*, Wiley, 1998.