Investigation and Prioritization of Performance Indicators for Inventory Management in the University Hospital

P. Sirisawat*, N. Hasachoo and T. Kaewket
Logistics and Supply Chain Management Program, School of Management,
Mae Fah Luang University, Chiang Rai, Thailand
*sirisawat.p@gmail.com

Abstract – **The objective of this study focus on the investigation and prioritization of the inventory performance indicators in the university hospital. The results of this study found that in the group of main criteria quality (Q) is the most important indicator for inventory management in the university hospital. For sub-criteria, patient safety e.g. delays, errors (Q4) is the most important indicators in the group of quality, replenishment time (T1) is the most important indicator in the group of the time, inventory cost (F1) is the most important indicators in the group of financial. Inventory turnover (P1) is the most important indicators in the group of productivity**

Therefore, the presented results of this study will help the people who do work in the healthcare industry or related industry for using to be the guideline for improving the performance of inventory management.

Keywords – **Performance indicators, fuzzy AHP, healthcare industry**

I. INTRODUCTION

Thailand is well-known for medical hub and wellness center. For the healthcare market in Southeast Asia (SEA), Thailand is in the second rank after Indonesia. The total healthcare market expenditure in Thailand is around 20% of the total expenditure in Southeast Asian countries. During the years 2007-2013, the revenue from the medical tourism markets of Thailand has increased around 194% which can generate around 4.7 billion USD in the year 2013[1]. Thailand's healthcare sector is growing rapidly from 12 billion USD to 19 billion USD between the years 2010-2015. And within the year 2020, it is forecasted to grow up to 28.5 billion USD [2].

Regarding the number of healthcare facilities in Thailand, there are 38,512 sites provide the healthcare service in which 33.9 % of the total healthcare service providers are state-funded healthcare providers (public primary care) e.g. district public health offices, public health centers, and community and general hospitals. 64.4 % of the total healthcare service providers are private clinics and the other 17 % of the total healthcare service providers are hospitals. The hospitals in Thailand consist of (54.1%) private hospitals and (45.9%) public hospitals [3].

The situation of state hospitals and private hospital in Thailand, 1) The situation of state hospitals: even though there are many state hospitals in every region of the country, they still face problems such as limited ability to serve the patient in some locations because of the lack of resources and insufficient supply of the state hospital beds to meet the customers demand. Besides, some of the outpatients have to wait for the treatment for a long time. Therefore, some groups of the customer who have sufficient spending power change to use the service of the private hospitals instead of state hospitals despite the higher cost of treatment in private hospitals than the cost of the treatment in the government hospital. 2) The number of private hospitals in Thailand in the year 2016 is 347 with 321 private hospitals in 2012. For the location distribution of private hospitals, there are 116 private hospitals in the central region of Thailand, which is around 33.4 % of all private hospitals in Thailand. 105 private hospitals are in Bangkok (30.3%), 52 are in the northern region (15%), 40 are in the northeast region (11.5%) and 34 are in the southern region (9.8%) [3].

Due to the rapid growth of the healthcare industry in Thailand, every hospital has to focus on both healthcare service levels and operational costs. Therefore, one of the important things that hospitals have to manage is inventory management. The inventory management plays an important role in helping the hospitals control the inventory level, reduce costs, wastes, and the risks of excess supply which causes the obsolescence of the hospital's inventory and also maintains the customer satisfaction of service and customer service level of the hospitals. Inventory management in the hospitals also affects the patient's life e.g. stock-out of the medicines, or other equipment where in other industries stock-out is a concern only for working process and profits [4].

For improvement of inventory management performance in hospitals, this paper aims to investigate the inventory management indicators for the new university hospital and prioritize the performance indicators. For data collection of this study, collected from the healthcare experts and used Fuzzy analytic hierarchy process (FAHP) method to analyze the data for ranking the inventory management indicators of the university hospital. The results of this study are presented in section IV.

II. LITERATURE REVIEW

A. *Performance indicators for inventory management*

For Performance indicators of inventory management in hospitals, some researchers who studied and divided the indicators into 4 groups which are in the following:

1) Quality (Q): It comprises of availability such as service level and stock-out. Patient safety such as delays and errors. Inventory visibility such as on-hand and safety stock. The criticality of inventory items [4-6].

2) Time (T): It comprises of replenishment time, clinical staff involvement, searching and picking time, and storage (holding) time [4,7].

3) Financial (F): It comprises of inventory cost, the value of stock, and stock wastage or obsolescence [4,6,8]

4) Productivity (P): It comprises of inventory turnover, utilization rate, and standardization [4,9,10]

TABLE I
PERFORMANCE INDICATORS FOR INVENTORY MANAGEMENT

Main Criteria	Sub-Criteria Code	Sub-Criteria	References
Quality (Q)	Q1	Availability (service level, stock-out)	[4-6]
	Q2	Inventory visibility (on-hand, safety stock)	
	Q3	Criticality of inventory items	
	Q4	Patient safety (delays, errors)	
Time (T)	T1	Replenishment time	[4,7]
	T2	Clinical staff involvement	
	T3	Searching and picking time	
	T4	Storage (holding) time	
Financial (F)	F1	Inventory cost	[4,6,8]
	F2	Value of stock	
	F3	Stock wastage or obsolescence	
Productivity (P)	P1	Inventory turnover	[4,9,10]
	P2	Utilization rate	
	P3	Standardization	

Several studies were conducted on the performance measurement for inventory management and related performance measurement in the healthcare industry. Moons et al., [4] studied the internal hospital supply chains which focused on the performance measurement of logistics activities. They also focused on the performance indicators of inventory management and distribution activities. Lenin [11] studied performance measurement in the healthcare industry. Therefore, the main focus of this study is the supply chain performance which comprises of the distributors, inbound and outbound transportation, the performance of suppliers, third-party logistics companies, etc. Kelle et al., [10] used the case study of the hospital to study inventory management and a pharmaceutical supply chain system. Dellaert and van de Poel [12] studied inventory management control of the academic hospital which tried to benchmark with the global inventory management control for improving the performance of inventory management. De Vries [13] analyzed the structure and shaping of stakeholders' inventory systems in the healthcare industry. They also focused on the exploratory in the case study of medicines inventory system for reshaping.

B. Fuzzy AHP

Fuzzy AHP is one of the important methods used to solve the problems, especially for decision-making problems. Büyüközkan and Çifçi [14] studied the electronic service quality in the healthcare industry which applied fuzzy AHP and fuzzy TOPSIS for analyzing the importance of each criteria. Sun [15] studied the model of performance evaluation in which fuzzy TOPSIS and fuzzy AHP were used to explain and understand more about the process of evaluation and the effective systematic decision.

Torfi et al. [16] applied both fuzzy AHP and fuzzy TOPSIS methods to solve the situation of the performance ratings that are vague and uncertain. Furthermore, they are used to find out the weight of the evaluation criteria and also ranked the alternatives. Vinodh et al. [17] have selected the method for plastic recycling by using fuzzy TOPSIS and fuzzy AHP approaches under the complex decision variables.

From the literature review, although many researchers studied the performance measurement in the hospital industry especially in the inventory management in the hospitals, there is no research paper studied on the ranking of the important indicators. Most of the research papers choose the indicators from the literature review and provide the same weight for each criterion when they evaluate the performance of their activities. Therefore, the fuzzy AHP method was used in this study for prioritizing the important performance indicators for inventory management in the university hospital before the decision-makers choose the inventory management indicators to evaluate their processes. The results of fuzzy AHP are presented in section IV.

III. METHODOLOGY

This study used both primary and secondary data where secondary data are based on the literature review from the journals, conference papers, news, etc. and the primary data includes an in-depth interview and questionnaire used for collecting date from the 5 experts in the healthcare logistics.

For ranking the inventory management performance indicators in the university hospital, the fuzzy AHP method was selected to analyze the data in which AHP method presented by Saaty [18] and it was developed by Chang [19] to adjust and solve about the limitation from AHP method. The processes of fuzzy AHP implementation are the following:

1. Figure 1 has shown the triangular fuzzy numbers (TFNs) memberships functions of $\tilde{A}$ on R and R→ [0, 1] illustrated as the equation below [15].

$$\mu\tilde{A}(x) = \begin{cases} \dfrac{(x - l)}{(m-l)}, & x \in [l, m], \\ \dfrac{(x - u)}{(m-u)}, & x \in [m, u], \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Parameter ($l \leq m \leq u$) from Eq. (1) presents about the possible value which fuzzy number $\tilde{A}$ comprise of u is the highest value, m is the best value, and l is the lowest value (Fig 1).

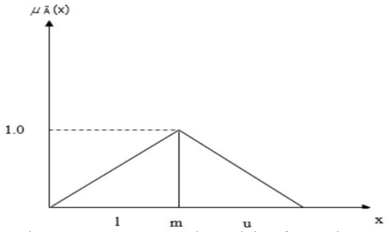

Fig 1. TFN Membership functions

From the consideration of two TFN, explained that $\tilde{A}=(a_1, a_2, a_3)$ and $\tilde{B}=(b_1, b_2, b_3)$ which in this study used Eq (2) to integrate two TFN.

$$\tilde{A}+\tilde{B} = (a_1, a_2, a_3) + (b_1, b_2, b_3) = (a_1+b_1, a_2+b_2, a_3+b_3) \quad (2)$$

Chang [19] proposed the extent analysis approach which explained as Eq. (3)

$$M_{g_i}^1, M_{g_i}^2, M_{g_i}^3, \ldots, M_{g_i}^m, \quad i = 1, 2, 3, \ldots, n, \quad (3)$$

Therefore, all the M_{gi}^j (j =1, 2, 3,…, m) are TFN which given in table II.

TABLE II
TRIANGULAR FUZZY NUMBERS AND LINGUISTIC VARIABLES

Linguistic variables	Fuzzy number	Triangle fuzzy number
Absolute importance	$\tilde{9}$	(8,9,10)
Intermediate	$\tilde{8}$	(7,8,9)
Very strong importance	$\tilde{7}$	(6,7,8)
Intermediate	$\tilde{6}$	(5,6,7)
Strong importance	$\tilde{5}$	(4,5,6)
Intermediate	$\tilde{4}$	(3,4,5)
Moderate importance	$\tilde{3}$	(2,3,4)
Intermediate	$\tilde{2}$	(1,2,3)
Equal importance	$\tilde{1}$	(1,1,1)

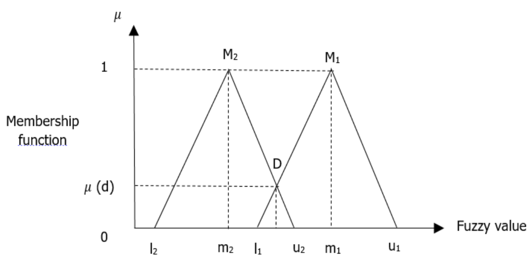

Fig 2. The presentation of intersection between two TFN

Step 1. The value of fuzzy synthetic extent with considering to i-th criteria could be defined with the equation below:

$$S_i = \sum_{j=1}^{m} M_{g_i}^{j} \times \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^{j}\right] \quad (4)$$

$$\sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{j=1}^{m} l_{ij}, \sum_{j=1}^{m} m_{ij}, \sum_{j=1}^{m} u_{ij}\right)$$

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^{j}\right] = \left(\frac{1}{\sum_{n}^{i=1}\sum_{m}^{j=1} u_{ij}}, \frac{1}{\sum_{n}^{i=1}\sum_{m}^{j=1} m_{ij}}, \frac{1}{\sum_{n}^{i=1}\sum_{m}^{j=1} l_{ij}}\right)$$

Step 2. Let $M_1 = (l_1, m_1, u1)$ and $M_2 = (l_2, m_2, u_2)$ to be two fuzzy synthetic extent values, the degree of possibility of $M2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ can be illustrated as:
$V(M_2 \geq M_1) = hgt(M_2 \cap M_1) = \mu(d)$

$$= \begin{cases} = 1 & \text{if } m_2 \geq m_1 \\ = 0 & \text{if } l_2 \geq u_2 \\ = \dfrac{l_1 - u_2}{(m_2 - u_2)\ (m_1 - l_1)} & \text{otherwise} \end{cases} \quad (5)$$

The possibility of convex fuzzy numbers degree greater than k convex fuzzy M_i (i=1,2,3,…, k) could be illustrated with the following equations:

$$V(M \geq M_1, M_2, \ldots, M_k)$$
$$= V[(M \geq M_1), (M \geq M_2) \text{ and} \ldots \text{and } (M \geq M_k)] \quad (6)$$
$$= \min V(M \geq M_i), \quad i = 1,2,3,4,5, \ldots, k$$

By assuming that $d'(A_i) = \min V(S_i \geq S_k)$ For k = 1,2,3,4,5, … ,n (k≠i), therefore, the weight vector is defined by

$$W' = (d'(C_1), d'(C_2), \ldots, d'(C_n))^T,$$

where C_i (i=1,2,3,4,5,…,n) are the weight value for the criteria.

Step 3. The process of the normalized weight of each criteria could be illustrated as:

$$W = (d(C_1), d(C_2), \ldots, d(C_n))^T, \quad (7)$$

IV. RESULTS

TABLE III
THE RESULTS OF AGGREGATED FUZZY DECISION MATRIX FOR Q-P

	Q			T			F			P			Weight	Rank
Q	(1.00,	1.00,	1.00)	(0.17,	1.08,	4.00)	(0.17,	3.28,	8.00)	(0.17,	6.04,	10.00)	0.257	1
T	(0.25,	2.47,	6.00)	(1.00,	1.00,	1.00)	(0.14,	5.63,	10.00)	(0.20,	1.85,	6.00)	0.256	2
F	(0.13,	2.12,	6.00)	(0.10,	1.33,	7.00)	(1.00,	1.00,	1.00)	(0.17,	1.29,	5.00)	0.244	3
P	(0.10,	1.11,	6.00)	(0.17,	1.34,	5.00)	(0.20,	2.25,	6.00)	(1.00,	1.00,	1.00)	0.243	4

TABLE IV
THE RESULTS OF AGGREGATED FUZZY DECISION MATRIX FOR Q1-Q4

	Q1			Q2			Q3			Q4			Weight	Rank
Q1	(1.00,	1.00,	1.00)	(0.25,	2.47,	9.00)	(0.33,	3.10,	8.00)	(0.10,	0.18,	0.50)	0.271	2
Q2	(0.11,	1.13,	4.00)	(1.00,	1.00,	1.00)	(1.00,	2.40,	7.00)	(0.11,	0.52,	3.00)	0.248	3
Q3	(0.13,	0.77,	3.00)	(0.14,	0.70,	1.00)	(1.00,	1.00,	1.00)	(0.10,	0.15,	0.25)	0.132	4
Q4	(2.00,	6.60,	10.00)	(0.33,	5.50,	9.00)	(4.00,	7.20,	10.00)	(1.00,	1.00,	1.00)	0.349	1

TABLE V
THE RESULTS OF AGGREGATED FUZZY DECISION MATRIX FOR T1-T3

	T1			T2			T3			T4			Weight	Rank
T1	(1.00,	1.00,	1.00)	(1.00,	4.60,	9.00)	(0.25,	2.07,	7.00)	(1.00,	3.60,	9.00)	0.267	1
T2	(0.11,	0.40,	1.00)	(1.00,	1.00,	1.00)	(0.20,	1.30,	5.00)	(0.14,	1.62,	8.00)	0.237	4
T3	(0.14,	1.13,	4.00)	(0.20,	2.05,	5.00)	(1.00,	1.00,	1.00)	(0.20,	2.38,	7.00)	0.248	2
T4	(0.11,	0.65,	1.00)	(0.13,	3.43,	7.00)	(0.14,	2.07,	5.00)	(1.00,	1.00,	1.00)	0.247	3

TABLE VI
THE RESULTS OF AGGREGATED FUZZY DECISION MATRIX FOR F1-F3

	F1			F2			F3			Weight	Rank
F1	(1.00,	1.00,	1.00)	(1.00,	3.40,	8.00)	(0.20,	1.92,	8.00)	0.348	1
F2	(0.13,	0.66,	1.00)	(1.00,	1.00,	1.00)	(0.14,	1.23,	6.00)	0.306	3
F3	(0.13,	1.83,	5.00)	(0.17,	3.24,	7.00)	(1.00,	1.00,	1.00)	0.346	2

TABLE VII
THE RESULTS OF AGGREGATED FUZZY DECISION MATRIX FOR P1-P3

	P1			P2			P3			Weight	Rank
P1	1.00	1.00	1.00	1.00	4.00	8.00	0.17	4.04	8.00	0.368	1
P2	0.13	0.51	1.00	1.00	1.00	1.00	1.00	4.80	8.00	0.339	2
P3	0.13	1.30	6.00	0.13	0.34	1.00	1.00	1.00	1.00	0.293	3

TABLE VIII
THE RESULTS OF FUZZY SYNTHETHIC EXTENT FOR MAIN CRITERIA Q-P

Q	=	(1.50, 11.40, 23.00)	x	(1/83.00, 1/33.79, 1/5.95)	=	(0.018, 0.337, 3.865)
T	=	(1.59, 10.95, 23.00)	x	(1/83.00, 1/33.79, 1/5.95)	=	(0.019, 0.324, 3.865)
F	=	(1.39, 5.73, 19.00)	x	(1/83.00, 1/33.79, 1/5.95)	=	(0.017, 0.170, 3.193)
P	=	(1.47, 5.70, 18.00)	x	(1/83.00, 1/33.79, 1/5.95)	=	(0.018, 0.169, 3.025)

TABLE IX
V-VALUE'S RESULTS FOR MAIN CRITERIA Q-P

	Q	T	F	P
Q	-	1	1	1
T	0.9965	-	1	1
F	0.9498	0.9536	-	1
P	0.9469	0.9509	0.9997	-

Table VIII illustrated the results of the fuzzy synthetic extent for main criteria Q-P which used the calculation from Eq. (4). The results of the degree of possibility (v-value) are presented in Table IX which used the Eq. (5) for calculation. The last step used the calculation process of Eq. (6) to find out the results of the minimum value of v-value which are illustrated as:

$d'(Q) = \min V(S_1 = S_k) = \min(1, 1, 1) = 1$

For other criteria, the same process was applied and the result are as followings;

$d'(T) = 0.9965$, $d'(F) = 0.9498$, and $d'(P) = 0.9469$

The result for the weight of mains criteria are given as:

$W' = (1, 0.9965, 0.9498, 0.9469)^T$

The final result for the weight of mains criteria were shown as:

$W = (0.257, 0.256, 0.244, 0.243)$

For the remaining of the criteria used the same process of calculation to find out the weights. Therefore, the final ranking of all criteria of performance indicators for inventory management in the university hospital are shown in Table X

TABLE X
All RANKING OF PERFORMANCE INDICATORS

Criterion	Weight	Sub-criteria	Weight	Finalized weight	Global rank
Quality (Q)	0.257	Q1	0.271	0.06962	8
		Q2	0.248	0.06374	10
		Q3	0.132	0.03388	14
		Q4	0.349	0.08960	1
Time (T)	0.256	T1	0.267	0.06827	9
		T2	0.237	0.06078	13
		T3	0.248	0.06360	11
		T4	0.247	0.06331	12
Financial (F)	0.244	F1	0.348	0.08493	3
		F2	0.306	0.07462	6
		F3	0.346	0.08442	4
Productivity (P)	0.243	P1	0.368	0.08958	2
		P2	0.339	0.08240	5
		P3	0.293	0.07123	7

V. CONCLUSION

This study focused on the investigation and prioritization of the performance indicators for inventory management in the university hospital. Therefore, the results of this study found that the highest weightage value of performance indicators for inventory management represented that Q, T, F, and P respectively which means Quality (Q) is the most important indicators for inventory management in the university hospital.

For sub-criteria of performance indicators for inventory management ranking values of indicator in the

978-1-7281-3804-6/19/$31.00 ©2019 IEEE

group of quality are Q4, Q1, Q2, and Q3 respectively which means that patient safety (delays, errors) is the most important indicators in this group. The ranking values of indicator in the group of time are T1, T3, T4, and T2 respectively which means that replenishment time is the most important indicators in this group. The ranking values of indicator in the group of financial are F1, F3, and F2 respectively which means that inventory cost is the most important indicators in this group. The last indicator for the ranking values of indicator in the group of productivity is P1, P2, and P3 respectively which means that inventory turnover is the most important indicators in this group.

REFERENCES

[1] Business Sweden, “Opportunities in Thailand’s Health Sector”, The Swedish Trade and Invest Council, May 2015.

[2] Alliance experts, “Thailand healthcare industry: growth and opportunities”. Source: https://www.allianceexperts.com /en/knowledge/countries/asia/opportunities-in-the-thai-healthcare-sector/, 2019.

[3] Krusri Research, “Private Hospital Industry”, Thailand industry outlook 2019-2020, February 2019.

[4] Moons K., Waeyenbergh G, and Pintelon L. “Measuring the logistics performance of internal hospital supply chains –A literature study, Omega 82 (2019) 205–217.

[5] Fong AJ, Smith M, and Langerman A. “Efficiency improvement in the operating room”. The Journal of Surgical Research, 2016; 204:371–83.

[6] Rossetti M, Buyurgan N, Pohl E, and Hall R. “Medical supply Logistics”. Handbook of Healthcare System Scheduling 2012:245–80.

[7] Landry S and Beaulieu M, “The challenges of hospital Supply chain management, from central stores to nursing units. In: Handbook of Healthcare Operations Management: Methods and Applications. New York: Springer; 2013. p.465–82.

[8] Aronovich D, Tien M, Collins E, Sommerlatte A, and Allain L, “Measuring sup- ply chain performance: guide to key performance indicators for public health managers. Arlington, Va.: USAID | DELIVER PROJECT, Task Order 1. May 2010.

[9] Nachtmann H and Pohl E. “The state of healthcare logistics: cost and quality improvement opportunities”. Center for Innovation in Healthcare Logistics, University of Arkansas;2009.

[10] Kelle P, Woosley J, Schneider H. “Pharmaceutical supply chain specifics and in- ventory solutions for a hospital case”.Operations Research for Health Care, 2012;1(23):54–63.

[11] Lenin K. “Measuring Supply Chain Performance in the Healthcare Industry”, Science Journal of Business and Management Volume 2, Issue 5, October 2014, Pages: 136 142

[12] Dellaert N, Van de Poel E. “Global inventory control in an academic hospital”. International Journal of Production Economics Volumes 46–47, December 1996, Pages 277284

[13] De Vries J. “The shaping of inventory systems in health services: A stakeholder analysis”. International Journal of Production Economics 133(1):60-69·September 2011.

[14] Büyüközkan ü, and Çifçi G. “combined fuzzy AHP and fuzzy TOPSIS based strategic analysis of electronic service quality in healthcare industry”, Expert Systems with Applications 39 (2012) 2341–2354.

[15] Sun C.C. “A performance evaluation model by integrating fuzzy AHP and fuzzy TOPSIS methods”, Expert Systems with Applications 37 (2010) 7745–7754.

[16] Torfi F., Farahani R. Z. and Rezapour S. “Fuzzy AHP to determine the relative weights of evaluation criteria and Fuzzy TOPSIS to rank the alternatives”. Applied Soft Computing 10 (2010) 520–528.

[17] Vinodh S., Prasanna M., and Hari Prakash N. “Integrated Fuzzy AHP–TOPSIS for selecting the best plastic recycling method: A case study”. Applied Mathematical Modelling 38 (2014) 4662–4672.

[18] Saaty, T.L., “Analytic hierarchy process”, McGraw Hill, 1980.

[19] Chang, D.Y., “Applications of the extent analysis method on fuzzy AHP”. European Journal of Operational Research, Vol 95, Issue 3, Dec1996, 649-655.