A model for vendor managed inventory by applying the economic order quantity with fuzzy demand

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Abstract: This paper presented a decision support model for VMI system by applying the economic order quantity (EOQ) with fuzzy demand. The model of fuzzy EOQ that has been developed in this study is intended to accommodate the fuzzy demand. Result of the study shows that the optimal quantity of fuzzy EOQ is influenced by the value of Δ_1 and Δ_2. It was known that the value of order quantity (q) will be increased if the decision-makers getting more optimistic regarding the upper limit of the sales forecast implementation. The model formulation that has been introduced fuzzy number for demand to accommodate uncertainty situation.

Keywords: decision support model; vendor managed inventory; VMI; fuzzy demand; economic order quantity; EOQ; supply chain.

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1 Introduction

Vendor managed inventory (VMI) is a strategy being recommended to manage supply chain operations (Borade and Bansod, 2009). VMI implies that the supplier is given full responsibility to manage the customer's inventory level. The main objective of the supply chain management is to minimise entire system costs and satisfying service-level requirements simultaneously (Rangwani et al., 2011). A supply chain includes all activities involved in delivering a product from the stage of raw material to the customer as a whole system. These activities include manufacturing, inventory control, distribution, warehousing, and customer service. Supply chain management coordinates and integrates all of these activities into a smooth process (Yuen, 2010). A major solution is to optimise output of activities the entire system.

Inventory has been considered as one of the major cost drivers of the supply chain operation. As such, decisions regarding inventory control have a significant effect on supply chain performance. In a common supply chain, each company is responsible for its own inventory control activities. VMI is one of the most topics discussed partnering initiatives for improving inventory efficiency. VMI has been widely adopted by many industries for years. Many companies have been success applied VMI such as the classical successes story the partnership between Wal-Mart and Procter & Gamble (Marques et al., 2008). Under VMI setting vendor coordinates and integrates all of these activities into a seamless process. VMI approach to cost minimisation of inventory implies that a business can compete in the global marketplace. This approach requires careful planning and coordination of all activities of the supply chain partners. Min (2009) suggests that the use of technology in businesses today and the availability of information in corporate databases require inventory managers to access an interactive decision support system (DSS). It allows the manager to evaluate the firm's alternatives with regard to supply and demand variability and find a solution that is satisfactory for the firm's supply chain and its partners.

We present a decision tool that can be applied as a decision support system by members of a supply chain network to reduce the inventory cost of entire system. DSS models are tools to support managers during their decision-making process. Structure of

DSS includes database and model base. For example, Ahuja and Hanna (2004) emphasise the importance of DSS in business-world decisions when quantitative models such as EOQ are applied as model base. VMI approach aimed to minimise cost of inventory implies that a business may success in the global marketplace while becoming an efficient entity by itself. Information becomes important factor to implement VMI. DSS requires model base that able to optimise all activities of the supply chain partners in VMI system. One of important decision in VMI system is order quantity (Mahamani and Rao, 2010).

Various types of uncertainties and imprecision is inherent in real inventory problems (Li et al., 2011). They are classically modelled using the approaches from the probability theory. However, there are uncertainties that cannot be appropriately treated by usual probabilistic models (Björk, 2008; Kalaiarasi and Ritha, 2011). The question arise how to define inventory optimisation tasks in such environment and how to interpret optimal solutions. In crisp inventory models, all the parameters in the total cost are known and have definite values without ambiguity; in addition the real variable of the total cost is positive. But, in reality, it is not so certain. Hence there is a need to consider the fuzzy economic order quantity (EOQ) as decision variable to optimise inventory total cost in supply chain operation (Mahata and Goswami, 2009).

This study aimed to develop a decision support model for VMI system by applying the EOQ with fuzzy demand. EOQ model is proven to be quite effective in its implementation for inventory control in various fields. Implementation is carried out through the reformulation of the EOQ basic model. Fuzzy EOQ model is implemented in structure of DSS. The paper is organised as follows. In the next section, literature review which is related to the problem followed by Section 3 which describes the modelling approach. Section 4 describes the proposed model. Application of the model to case illustration and some benefit the model is discussed in Section 5. Finally, in Section 6, conclusions are presented.

2 Literature review

2.1 Vendor managed inventory

VMI as a business strategy is focused to improve service level and inventory turnover. It can perform which the buyer provides certain information of demand to a supplier. Supplier responsibility is maintaining the inventory level in a factory or warehouse. Performance measure in supply chain management usually derives from understanding and managing the relationship between inventory total cost and the customer service level. Recently, the most attractive of VMI research is determination of order quantity to minimise the inventory total cost and to maximise the buyer service level. Pasandideh et al. (2010) classified VMI research into two groups:

a simulation procedure application for managerial and functional subjects

b analytic and mathematical formulation for economic analysis.

Specifically, Achabal et al. (2001) and Marques et al. (2008) have summarised some benefit of VMI such as to maintain surplus capacity, to reduces the buffer stocks, to ensure responsive of customer, better resource utilisation, greater coordination, replacement product can be facilitated by VMI. VMI application was also designed with that of full channel coordination, and it was good impact in the short term. Many researchers formulated appropriate mathematical models for a buyer-supplier channel structure. They examined the effects of a VMI strategy such as the various cost components (Chen and Lin, 2010), role in a supply chain initiative (Borade and Bansod, 2009), integration production and transportation (Dhanalakshmi et al., 2009). In particular, the effects of an integrative VMI programme on total relevant costs and profits were investigated. Several common assumptions that also were used in their inventory-channel coordination research were: the inventory system of the buyer can be described by an EOQ policy, the demands are deterministic, there are no stock outs, the lead times are also deterministic, but several of cost was fuzzy (Gani and Maheswari, 2011).

Recently, DSS have become a part of the extended enterprise and serve as a platform for collaboration between business partners in the supply chain by providing decision-making support to improve supply chain performance. DSS has become an interactive that allows the manager to manage supply and demand variability. Achabal et al. (2011) designed DSS that combined inventory optimisation and promotional respond. Mahamani and Rao (2010) presented DSS using spreadsheet that applied EOQ crisp. This paper presents a new DSS that apply EOQ with fuzzy demand. Beheshti (2010) introduced a DSS that allows decision makers along the supply chain to employ a series of what-if analyses to evaluate different scenarios with regard to lowering the cost of products reaching the consumer.

2.2 Fuzzy inventory system

Inventory models that apply fuzzy theory have been mathematically developed. Syed and Aziz (2007) applied the signed distance method to the EOQ model with ordering cost and storage cost of fuzzy conditions. The comparison result showed that the ordering quantity of the fuzzy model was larger than the crisp model. Yao and Chiang (2003) compared the centroid defuzzification and signed distance methods on the EOQ model with fuzzy total inventory cost and fuzzy storing cost. The comparison results showed that the signed distance method gives better result. The direction of further model development was to consider various conditions in inventory policy with fuzzy conditions.

Lee and Yao (1998) discussed economic production quantity (EPQ) model with fuzzy demand and fuzzy production using triangular membership function. The discussion substance was the computation scheme by applying centroid method. Lee and Yao (1999) also discussed the EOQ model with fuzzy ordering quantity and fuzzy total inventory cost using centroid method. The similarity between these two models was the application of centroid method and triangle membership functions, while the difference was the applied inventory model. Chen and Hsieh (2000) developed a principal functions method that could be applied to trapezoidal and triangle membership functions. The discussion was still focused on the mathematical explanation that was intended to produce computing scheme only. The application of the model development was the inventory EOQ model.

Various consideration proposed by Chiang et al. (2005) that considered the stock out cost with all fuzzy conditions inventory parameters. Membership function that used was triangular fuzzy number (TFN) with defuzzification using signed distance method. Focus of the discussion was only on the computational scheme to improve the accuracy of the calculation results. Chen et al. (2007) developed an EPQ inventory model by considering that there were inferior products and fuzzy conditions on demand, the cost of storage and preparation costs. The used defuzzification method was the principal function with the trapezoidal membership function. The completion techniques for inventory model which is containing the fuzzy condition on model component were also developed. Gao and Feng (2006) developed an inventory model with fuzzy condition on demand and considering the product sales price discount rate.

A very complex mathematical formulation was solved by assigning a framework that consists of hybrid intelligent algorithm and dynamic programme. Kumal and Raju (2008) developed an inventory model that considered the stock out cost and product damage. The model was formulated with two objective, those were revenue maximisation and minimisation of waste product cost. The developed model solution techniques were the weighted non-linear fuzzy programming, fuzzy additive goal programming and the integration of those two techniques. The discussion was aimed to compare those solving techniques without concluding which completion technique was better. Taleizadeh et al (2009) developed the inventory model with fuzzy conditions on demand. The model solving technique uses particle swarm optimisation. This solving technique was also used by Xiaobin et al. (2007) for inventory model with fuzzy conditions preparation cost and storage cost. Inventory model development in paper industries can be found in the paper discussed by Björk (2008). The developed EPQ model aimed to get the optimum supply cycle time. Fuzzy condition was defined in the inventory cycle time with triangular membership function. Model finishing was carried on analytically.

3 Modelling approach

Modelling approach has developed refer to Pasandideh et al. (2010) that has proposed a good framework. In order to determine the impact of important supply chain parameters on the cost savings to be realised from collaborative initiatives such as VMI, consider a two-level supply chain consisting of a single manufacturer and a single supplier as a buyer. Although many of the results can be generalised to more complex supply chains, a simple supply chain is used for computational ease. We assume that the supplier faces external demand from consumers.

In a supply chain with VMI, the manufacturer information system directly receives consumer demand data. As a consequent, the manufacturer now has the combined inventory with order setup and holding cost. The supplier with regard to its own inventory cost, which equals the total cost of the supply chain, determines the timing and the quantity of production in every cycle. The major difference between not using and using VMI is that the supplier's order quantity is determined by the manufacturer in a VMI system.

Order quantity decision modelled using EOQ with fuzzy demand consideration. Fuzzy number that selected in this study is TFN. We are defuzzify mathematical formulation as solution model using signed distance method (Yao and Su, 2008). For each $a \in R$ in signed distance method defined $d_0(a,0) = a$. If $a > 0$, distance from a to 0 is $d_0(a,0) = a$. If $a < 0$, distance from a to 0 is $-d_0(a,0) = -a$. This is become main reasoning that form $d_0(a,0)$ is signed distance method from a to 0. If $\tilde{A} = (a,b,c) \in F_N$ and α-*cut* $0 \leq \alpha \leq 1$ from $\tilde{A}$ is $A(\alpha) = [A_L(\alpha), A_R(\alpha)]$. Signed distance from $A_L(\alpha)$ and $A_R(\alpha)$ to 0 is

$d_0(A_L(\alpha),0) = A_L(\alpha)$ and $d_0(A_R(\alpha), 0) = A_R(\alpha)$, respectively. Definition of signed distance from 0 to $[A_L(\alpha), A_R(\alpha)]$ is $d_0([A_L(\alpha), A_R(\alpha)], 0) = \frac{1}{2}[d_0(A_L(\alpha), 0) + d_0(A_R(\alpha), 0)]$. We can get $\frac{1}{2}[A_L(\alpha) + A_R(\alpha)] = \frac{1}{2}[a + c + (2b - a - c)\ \alpha]$ (Yao and Chiang, 2003). It is continue function from α in $0 \le \alpha \le 1$. Average is obtained from integration. If $\tilde{A} = \bigcup_{0\le\alpha\le 1}\left[A_L(\alpha)_\alpha, A_R(\alpha)_\alpha\right]$ will obtained definition if $\tilde{A} = (a,b,c) \in F_N$ signed distance from $\tilde{A}$ to $\tilde{0}$ is $d(\tilde{A},\tilde{0}) = \int_0^1 d\left(\left[A_L(\alpha)_\alpha, A_R(\alpha)_\alpha\right],\tilde{0}\right)d\alpha = \frac{1}{4}(2b+a+c)$ (Yao and Chiang, 2003; Yao and Su, 2008).

4 The proposed model

4.1 Fuzzy EOQ formulation and solution

The fuzzy EOQ mathematical model that will be formulated on the basis of the following assumptions:

a single-supplier–single-buyer supply chain with one item is considered

b shortage is not allowed

c replenishment of orders are assumed to be instantaneous, that is, the lead time is zero

d demand is fuzzy

e production rate is infinite

f product price is always fixed in the planning horizon.

The elements of the integrated inventory system consists of demand (*d*) from the customer, that is an effort to meet the sales plan or shipment, and ordering quantity (*q*), that is the amount of economic supply to the buyer. High and low number of request is defined as fuzzy number $(\tilde{d})$ with triangular membership function. The involved cost components are vendor ordering cost (k_v), retailer or buyer ordering cost (k_b), storage cost at retailer (*h*), and transportation cost from vendor to retailer (*c*). Total inventory cost of integrated inventory system as TC (*q*) is the sum of all associated costs, as follows:

$$TC(q) = \left(\frac{k_v \otimes \tilde{d}}{q}\right) \oplus \left[\left(c \otimes \tilde{d}\right) \oplus \left(\frac{k_b \otimes \tilde{d}}{q}\right) \oplus \frac{hq}{2}\right] \quad (1)$$

Demand is expressed as TFNs. If the demand is symbolised by $\tilde{d}$ then there is be difference of Δ. It means that is determined by decision makers based on their knowledge and experience. The Δ values will contribute to the demand value difference of $d - \Delta_1$ or $d + \Delta_2$, where *d* is a known number from the previous forecast. Fuzzy value of $\tilde{d}$ can be written as follows:

$$\tilde{d} = \left(d - \Delta_1, d, d + \Delta_2\right) \tag{2}$$

Total inventory cost will be in the form of fuzzy where $TC(q)$ is (H_1, H_2, H_3) in condition where $H_2 > H_1$ and $H_3 > H_2$. The values of H_1, H_2 and H_3 can be formulated:

$$H_1 = TC(q) - c\Delta_1 - \frac{(k_v + k_b)\Delta_1}{q} \tag{3}$$

$$H_2 = cd + \frac{(k_v + k_b)d}{q} + \frac{hq}{2} \tag{4}$$

$$H_3 = TC(q) + c\Delta_2 + \frac{(k_v + k_b)\Delta_2}{q} \tag{5}$$

Defuzzification can be done using signed distance method in accordance with the basic formula (Yao and Chiang 2003) with the following results:

$$d\left(TC(p), 0\right) = cd + \frac{(k_v + k_b)d}{q} + \frac{hq}{2} + \frac{1}{4}\left\{c\left(\Delta_2 - \Delta_1\right) + \frac{(k_v + k_b)(\Delta_2 - \Delta_1)}{q}\right\} \tag{6}$$

Optimal value of ordering quantity q^* is obtained by getting the first derivative of Equation 6. Conditions that need attention are $0 < \Delta_1 < d$ and $\Delta_2 > 0$.

$$\frac{(k_v + k_b)\left\{4d + (\Delta_2 - \Delta_1)\right\}}{4q^2} = \frac{h}{2}$$

$$q^* = \sqrt{\frac{(k_v + k_b)(4d + \Delta_2 - \Delta_1)}{2h}} \tag{7}$$

In the case of demand in firmly form or in exact number then the elements of difference Δ_1 and Δ_2 are equal to zero or $\Delta_1 = \Delta_2 = 0$. Equation (7) for condition $\Delta_1 = \Delta_2 = 0$ will be the equation from the EOQ basic model. The total inventory cost by considering fuzzy demand is represented as follows:

$$TC(q^*) = cd + \frac{(k_v + k_b)d}{q^*} + \frac{hq^*}{2} + \frac{1}{4}\left\{c\left(\Delta_2 - \Delta_1\right) + \frac{(k_v + k_b)(\Delta_2 - \Delta_1)}{q^*}\right\}$$

$$TC(q^*) = cd + \frac{1}{4}c\left(\Delta_2 - \Delta_1\right) + \frac{1}{2}\sqrt{2h(k_v + k_b)(4d + \Delta_2 - \Delta_1)} \tag{8}$$

If the equation of fuzzy total inventory cost is compared to the total inventory cost of firm EOQ model, it is differentiated by elements Δ_1 and Δ_2. If $\Delta_1 = \Delta_2 = 0$, then it will go back into EOQ.

Optimal point which has been obtained can be proven by examining the second derivative of the total inventory cost function.

$$\frac{d^2TC(q)}{dq^2} = \frac{(k_v + k_b)\left\{4d + (\Delta_2 - \Delta_1)\right\}}{8q^3} \tag{9}$$

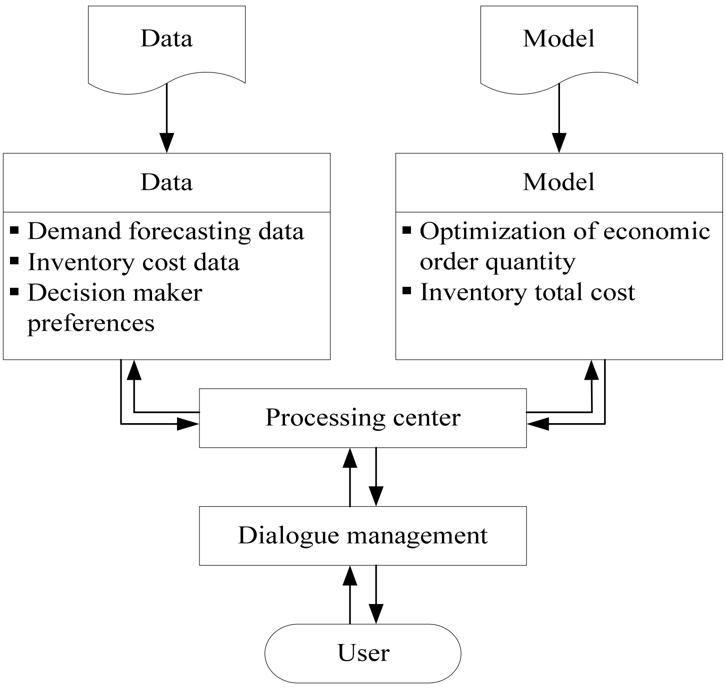
We obtain that $\frac{d^2TC(q)}{dq^2} > 0$ will be positive. We has proof that q^* is the optimal value, so that it will produce the minimum total inventory cost. Fuzzy value of d for the total inventory cost function will give a positive. It can proof with the following explanation:

$$4d + \Delta_2 - \Delta_1 = 3d + \Delta_2 + (d - \Delta_1) \tag{10}$$

4.2 Structure of the model

There are two components to apply above formulation. First, set the value of Δ_1 and Δ_2 based on the opinions of decision makers and second, prepare data that associated with shipping cost (c), vendor ordering cost (k_v), retailer or buyer ordering cost (k_b), the storage cost (h) and demand (d) that refer to forecast result. After kinds of data are available, the calculation of EOQ and the total inventory costs can be carried out based on the formula that has been formulated. Structure of the model consists of inventory total cost and defuzzification technique. DSS need parameters of cost, demand bias and sales or demand forecasting data that can be updated as circumstances change in the company. Structure of model can be seen in Figure 1.

Figure 1 Planned DSS



Model formulation has implemented using software Matlab 2009b that can be seen in Figure 2. Verification was conducted by tracing the running programme first. If the entire line of programme code was successfully executed according to the logic then programme would be considered successful. Next examination was the examination of result or output of the computer programme. A good model would produce solution that met to the model requirements. If the completion of the programme indicated any error and did not work according to the defined logic, then it would be corrected. Verification process had been carried out and model was able to work in accordance with the assumed logic and conditions.

Figure 2 DSS prototype (see online version for colours)

Determination of inventory can be determined based on the sales forecast. Forecast made for the next 12 months. The goal was to know the sales forecast every month that would be the input in determining the quantity of the economic supply each month. In Figure 2, elements of model has presented such as demand (d), order size (q), inventory total cost (TC) and parameters of model as a DSS prototype.

Other inputs that are required are parameters of cost and demand interval limit. Data of inventory cost for k_v = IDR 1,546,050, k_b = IDR 1,446,668, c = IDR 54 per ton and h = IDR 9.07 per ton per month. The limits of demand value that are accommodated by fuzzy parameter are obtained based on the opinion of the decision makers, those are $\Delta_1 = 0.1d$ and $\Delta_2 = 0.05d$. Parameter input in software can be shown in Figure 2. We called our DSS model as VMI@SaVe.

5 Implications

Computer has been became success key in implementation of VMI. It has often depends on computer platforms and information technology that used for product identification and tracking-tracing systems. Normally, these systems are already in place at both the retailer and supplier sides. Software systems are the most important because they facilitate such discussions as replenishment quantity and timing; safety stock levels, transportation routing and inter facility transhipments. VMI is an approach which reduces the information across the partners of supply chain, guarantying tangible benefits such as the increase in buyer profit, vendor profit, decrease in sales price and contract price an intangible benefits such as reduced inventory, replenishments, stock outs, and the most important, and reduce the bullwhip effect.

An inventory is a stock of goods that is kept ensuring demand fluctuation, which varies according to the nature of the business itself. Raw materials, purchased parts, partially finished items and finished goods, spare parts for machines, tools, and many other supplies are kind of goods might be supplied. Inventory management is a core process in the operations of supply chain management activity. Huang et al. (2008) suggest that good management of inventory is become very important and success key for most businesses and their supply chains. Poor inventory management has its harms to the business, decreases customer satisfaction and might demolishes it, and increase operating costs.

In order to perform good inventory management, a good model has to be followed. Inventory modelling determines the appropriate level of goods that a business must maintain in inventory in order to ensure demand fluctuation and smooth operation. The basis of such a model is to balance the cost of capital resulting from holding too much inventory against the penalty cost resulting from inventory shortage. VMI has good option as one of solution to increase business competitive advantage.

As a symbiotic partnership, VMI makes it less likely that a business will unintentionally become out of stock of a good and reduces inventory in the supply chain operation. Furthermore, company that would like to implement a model must familiar with the features of the product line, all the while helping to clean and organise their product lines. One of the keys to making VMI work is shared risk. Rihs (2009) was discussed practical implication of risks on supply chain operations. In this paper, existing of demand in fuzzy number is representing uncertainty situation that potential as demand risk. There are two cases anticipated by VMI. First, often if the inventory does not sell, damage, and complaint by end consumers the vendor can repurchase the product from the retailer. This mechanism is called as reverse logistic and supply chain operation. Second, the product may be in the possession of the retailer but is not owned by the retailer until the sale takes place, meaning that the retailer simply houses the product in exchange for a predetermined commission. In this case, VMI is usually applied but not mandatory to be used.

In order for smooth implementation the model, we must to be aware of the importance of model implementation in VMI framework, why there exists for inventory in supply chain management are given below:

- consider decision makers preference (Δ_1 and Δ_2)
- to meet customer demand with fuzzy preference
- smooth production requirements to ensure supply operation on schedule
- decouple operations, such as using inventory buyers
- not allowed stock outs

- not allowed quantity discounts
- take advantage of order cycles
- price stability

VMI helps foster a closer understanding and collaboration between the supplier and retailer. Forecasting and demand management become important factors as inventory correction procedure in VMI. It would be impossible to automate a VMI implementation or have one even somewhat close to accurate without an information system.

6 Conclusions

Role of decision support model is to assist supply chain decision makers to negotiate and make decisions that are the best for the VMI system implementation. This study has success to develop a decision support model for VMI system by applying the EOQ with fuzzy demand. Calculus optimisation has provided a powerful solution to determine q^* optimal as main element of decision support. We have developed an optimisation technique for a single echelon supply chain system to show that supply chain optimisation has involved members work together to improve efficiency of the VMI system. Model developed to obtain benefit from trickle down effects.

Theoretically, the main contribution of this model is a mathematical model that can be applied in an entire supply chain system. Model can facilitate its members to get benefits in cooperation with regard to inventory management. A further contribution is the development of multi echelon problem that can be used to evaluate more complex system. In other side, cost of deviation analysis is interesting information that analyse in deep from the optimum by any member of the chain. The model is also integrated in incorporating e-commerce and just-in-time (JIT). The model formulation that has been introduced fuzzy number for demand to accommodate uncertainty situation.

The major limitation of this DSS can be rectified by integration with information system. However the VMI success impacted by the quality of buyer-supplier relationships, the quality of the information system or technology and the intensity of information sharing, but not by the quality of information shared. The major barriers of VMI system are willingness to share data, ability to share data and ability to use the shared information properly. Interactive decision making process with multi person multi criteria need develop for further research in VMI system development.

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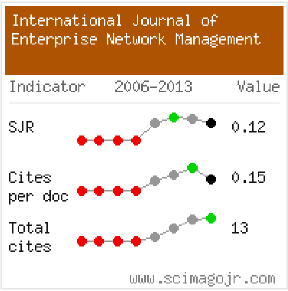

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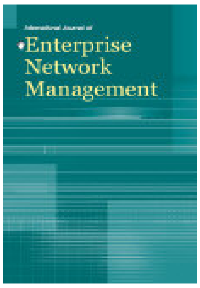

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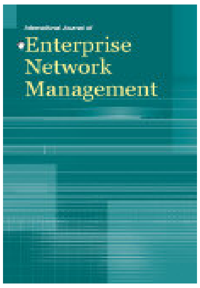

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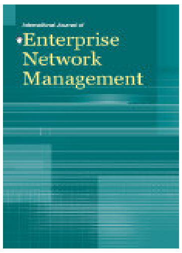

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