

Comparative research on three-echelon and two-echelon medicine inventory model with positive lead-time

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Abstract: According to the principle of minimizing total cost, the three-echelon optimized medical inventory model with stochastic lead-time and two-echelon optimized medicine inventory model with fixed lead-time are established. The relationship between lead-time and inventory cost is studied by Matlab software. It shows that the variety of lead-time has an important effect on medicine inventory systems. Numerical simulation and sensitivity analysis of two models are presented by Lingo software. Based on analysis, it is concluded that the two-echelon model with lead-time results in inventory cost savings, and keeps the quality of care as reflected in service levels when compared with the three-echelon network structure.

Key words: healthcare supply chain; inventory management; lead-time; optimization model

More and more attention has been paid to the research on healthcare supply chains in recent years, but most of them are limited to qualitative analysis. Little quantitative work has been done on healthcare supply chains and the management of medicine inventory. The idea of outsourcing medicine inventory to professional logistics companies was presented by Prashant^[1] and Lunn^[2]. They analyzed the advantages and disadvantages of outsourcing medicine inventory. Based on this idea, Nicholson et al. addressed a comparison of inventory costs and service levels of an in-house three-echelon distribution network vs. an outsourced two-echelon distribution network when they did research on the medicine stochastic inventory model^[3]. But the inventory model of Ref. [3] concentrated only on the stochastic customer demand, without considering the effect of lead-time on medicine inventory. However, the variety of stochastic lead-times is a major factor affecting inventory optimization in the whole supply chain^[4–8]. Therefore, according to the reality of medicine circulation in China, the inventory theory based on positive replenishment lead-time will be applied in the basic models of Ref. [3] in this paper. Numerical simulation and sensitivity analysis of two modified models are presented.

1 Medicine Inventory Model with Positive Replenishment Lead-Time

At present, medicine is usually distributed to large hospital warehouses from a central warehouse, and then distributed to department warehouses from hospital warehouses. Therefore, this is a three-echelon network system. With the quick development of healthcare supply chains, the response speed of non-critical medicine supplies is improved greatly. In order to optimize the medicine inventory level, it is considered that hospital warehouses should be cancelled. Demands should be transferred directly from department warehouses to a third-party-logistics (TPL) service central warehouse, thus, reducing to a two-echelon network system. In the three-echelon medicine inventory model, there exists stochastic lead-time from manufacturer to a logistics central warehouse and from a logistics central warehouse to a hospital warehouses. On the other hand, it is reasonable to consider lead-time from manufacturer to a logistics central warehouse as a fixed constant because of the cooperation in the two-echelon medicine inventory model. The manufacturers have to deliver medicine to a service central warehouse in a determined amount of time.

1.1 Assumptions

Models are set up on the basis of the following assumptions:

① Single non-critical items in inventory models is considered for each network. In order to capture the key realities in healthcare systems, it is assumed that there is a periodic review of the par level inventory management system for each echelon, and all echelons have the same review period.

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② Each of the two models is represented as an arborescent multi-echelon distribution system. Essentially, each system is represented as one in which a lower echelon receives items from only one source at a higher echelon. In this paper, the demand for the single item is assumed to be independent across hospitals and across departments within a hospital.

③ To carry out a fair and unbiased comparison of the two alternative networks, it is important to assume no item price differentials across echelons.

④ The relevant costs incorporated in our models focus on the traditional inventory holding and backorder costs at each echelon. The replenishment lead-time sums up the stochastic delay time and the stochastic transport time.

⑤ Consistent with current realities in healthcare, it is assumed that all backorders are satisfied by emergency deliveries at a cost higher than normal delivery cost. Furthermore, it is required that each department must meet a minimum service level (in terms of the minimum fraction of demand which should be satisfied).

1.2 Three-echelon model

Suppose that there are N hospitals and each hospital i has a hospital warehouse as well as three department warehouses (in-house, clinic and emergency). Suppose that x_{ij} , x_i and x_w represent demand for department j in hospital i , hospital i and central warehouse in the same review period, respectively. It is assumed that $x_{ij} \sim N(\mu_{ij}, \sigma_{ij})$ and $f(x)$ represents the probability density function (PDF) of review period demand. Let H_{ij}^1 , H_i and H_w represent unit-holding cost for department j in hospital i , hospital i and central warehouse, respectively. Let P_{ij}^1 , P_i and P_w represent unit penalty (backorder) cost for department j in hospital i , hospital i and central warehouse, respectively. In this model, the decision variables are R_{ij}^1 , R_i and R_w , which represent the par levels for each department, each hospital and the central warehouse. In determining the department par levels, we also ensure that a minimum pre-specified service level δ_{ij} (which represents the proportion of demand satisfied through inventory) for each department j in hospital i is maintained. Thus, the par level R_{ij}^1 for each department j in hospital i is determined such that it is associated with service level β_{ij}^1 which is at least as large as the minimum pre-specified service level δ_{ij} . But the fact is that the inventory of the central warehouse and the hospital warehouses are all controlled separately in China at present. According to the idea of supply chain competition, it is reasonable to consider a centralized decision-making authority in medicine supply chains tomorrow. Based on the above, a model based on the premise of a review period is presented as follows:

$$\begin{aligned} \min C_{EI}(R_w, R_i, R_{ij}^1) = & H_w \left[\int_0^{R_w} (R_w - x_w) f(x_w) dx_w \right] + P_w \left[\int_{R_w}^{\infty} (x_w - R_w) f(x_w) dx_w \right] + \\ & \sum_{i=1}^N H_i \left[\int_0^{R_i} (R_i - x_i) f(x_i) dx_i \right] + \sum_{i=1}^N P_i \left[\int_{R_i}^{\infty} (x_i - R_i) f(x_i) dx_i \right] + \\ & \sum_{i=1}^N \sum_{j=1}^3 H_{ij}^1 \left[\int_0^{R_{ij}^1} (R_{ij}^1 - x_{ij}) f(x_{ij}) dx_{ij} \right] + \sum_{i=1}^N \sum_{j=1}^3 P_{ij}^1 \left[\int_{R_{ij}^1}^{\infty} (x_{ij} - R_{ij}^1) f(x_{ij}) dx_{ij} \right] \end{aligned} \quad (1)$$

such that

$$\int_{R_{ij}^1}^{\infty} (x_{ij} - R_{ij}^1) f(x_{ij}) dx_{ij} - (1 - \beta_{ij}^1) \mu_{ij} \leq 0 \quad i = 1, 2, \dots, N; j = 1, 2, 3 \quad (2)$$

$$R_i - \sum_{j=1}^3 \left[R_{ij}^1 - \int_0^{R_{ij}^1} (R_{ij}^1 - x_{ij}) f(x_{ij}) dx_{ij} \right] \geq 0 \quad i = 1, 2, \dots, N \quad (3)$$

$$R_w - \sum_{i=1}^N \left[R_i - \int_0^{R_i} (R_i - x_i) f(x_i) dx_i \right] \geq 0 \quad (4)$$

$$\beta_{ij}^1 \geq \delta_{ij} \quad (5)$$

$$R_w, R_i, R_{ij}^1 \geq 0 \quad i = 1, 2, \dots, N; j = 1, 2, 3 \quad (6)$$

The objective function sums up the holding costs based on expected inventory levels at all three echelons (central warehouse, hospital warehouses, and department warehouses within each hospital) and also assesses a penalty cost for expected backorders for departments (see Eq. (1)). Constraint (2) is the relationship between the expected demand satisfied and the inventory of department j in hospital i based on service level β_{ij}^1 . Constraints (3) and (4) capture the realities of the three-echelon network for the healthcare system studied in this paper. Recall that replenishments are communicated by the departments at the beginning of the review interval and are executed as received by the hospital warehouse, and, subsequently, replenishments are communicated by hospital warehouses at the be-

ginning of the review interval and executed as received by the central warehouse. Based on this, each hospital warehouse needs to maintain adequate inventories (as determined by par levels R_i) to satisfy the expected replenishments for all departments it supplies and the central warehouse needs to maintain inventories (reflected in the par level R_w) to satisfy the expected replenishments for all hospital warehouses. This feature is incorporated in this set of constraints. Obviously, β_{ij}^1 is constrained to be at least as large as δ_{ij} which is the pre-specified minimum service level that should be maintained for any department (see constraint (5)). Finally, the non-negativity constraints on the decision variables are incorporated in constraint (6).

According to the model of Ref. [4], it is assumed that the stochastic delayed time caused by the outside supplier to the central warehouse is $\tau_w, \tau_w \sim N(\mu_{\delta_w}, \sigma_{\delta_w})$. The stochastic transport time caused by the outside supplier to the central warehouse is $T_w, T_w \sim \gamma(\alpha_w, \beta_w)$. Then

$$E(\tau_w) = \int_0^\infty \left[1 - \Phi\left(\frac{x_w - \mu_{\delta_w}}{\sigma_{\delta_w}}\right) \right] dx_w = \sigma_{\delta_w} \Phi^{(1)}(-\mu_{\delta_w} \sigma_{\delta_w}) \quad (7)$$

$$V(\tau_w) = \sigma_{\delta_w}^2 (1 - P(\tau_w = 0)) + E(\tau_w) \mu_{\delta_w}^2 - (E(\tau_w))^2 \quad (8)$$

where $P(\tau_w = 0) = \Phi(-\mu_{\delta_w} \sigma_{\delta_w})$. Considering stochastic lead-time $T_{s,w}$, the mean and standard deviation of $T_{s,w}$ are

$$E(T_{s,w}) = E(T_w) + E(\tau_w) = \frac{\alpha_w}{\beta_w} + E(\tau_w) \quad (9)$$

$$V(T_{s,w}) = V(T_w) + V(\tau_w) = \frac{\alpha_w^2}{\beta_w} + V(\tau_w) \quad (10)$$

Then the mean demand and standard deviation of demand for the central warehouse with stochastic lead-time $T_{s,w}$ are

$$E(T_{s,w}D) = \mu_w E(T_{s,w}) \quad (11)$$

$$V(T_{s,w}D) = \sigma_w^2 E(T_{s,w}) + \mu_w^2 V(T_{s,w}) \quad (12)$$

According to the maximum entropy theory, it is clear that the demand for the central warehouse with stochastic lead-time is $T_{s,w}$, where $T_{s,w} \sim N(E(T_{s,w}D), V(T_{s,w}D))$. The stochastic delay time caused by the central warehouse to hospital i warehouses is τ_i , where $\tau_i \sim N(\mu_{\delta_i}, \sigma_{\delta_i})$. The stochastic transport time caused by the central warehouse to hospital i warehouses is T_i , where $T_i \sim \gamma(\alpha_i, \beta_i)$. Then the mean demand and standard deviation of demand for hospital i warehouses with stochastic lead-time $T_{s,i}$ satisfy $T_{s,i} \sim N(E(T_{s,i}D), V(T_{s,i}D))$. Where

$$E(T_{s,i}D) = \mu_i \left[\frac{\alpha_i}{\beta_i} + \sigma_{\delta_i} \Phi^{(1)}(-\mu_{\delta_i} \sigma_{\delta_i}) \right] \quad (13)$$

$$V(T_{s,i}D) = \sigma_i^2 \left[\frac{\alpha_i}{\beta_i} + E(\tau_i) \right] + \mu_i^2 \left[\frac{\alpha_i^2}{\beta_i^2} + \sigma_{\delta_i}^2 (1 - P(\tau_i = 0)) + E(\tau_i) \mu_{\delta_i} - (E(\tau_i))^2 \right] \quad (14)$$

where $P(\tau_i = 0) = \Phi(-\mu_{\delta_i} \sigma_{\delta_i})$. It is noted that the demand for hospital i warehouses is $\mu_i = \sum_{j=1}^3 \mu_{ij}$, the standard

deviation of the demand for hospital i warehouses is $\sigma_i = \sqrt{\sum_{j=1}^3 \sigma_{ij}^2}$. Similarly, the demand for the central ware-

house is $\mu_w = \sum_{i=1}^N \mu_i$, the standard deviation of the demand for the central warehouse is $\sigma_w = \sqrt{\sum_{i=1}^N \sigma_i^2}$.

According to Ref. [9], the maximum medicine inventory of the central warehouse is $R_w = E(T_{s,w}D) + k \sqrt{V(T_{s,w}D)}$ and the maximum medicine inventory of hospital warehouses is $R_i = E(T_{s,i}D) + l \sqrt{V(T_{s,i}D)}$, where k and l represent safety factors for the central warehouse and hospital warehouses, respectively. Integrating R_w, R_i and Eq. (1), and standardizing the demand, it is concluded that

$$\begin{aligned} C_{E,1}(R_w, R_i, R_{ij}^1) &= [(H_w + P_w)k\Phi(k) - (H_w + P_w)G(k) - P_w k] \sqrt{V(T_{s,w}D)} + \\ &\left[\left(\sum_{i=1}^N H_i + \sum_{i=1}^N P_i \right) l\Phi(l) - \left(\sum_{i=1}^N H_i + \sum_{i=1}^N P_i \right) G(l) - \left(\sum_{i=1}^N P_i \right) l \right] \sqrt{V(T_{s,i}D)} + \\ &\sum_{i=1}^N \sum_{j=1}^3 H_{ij}^1 \left[\int_0^{R_{ij}^1} (R_{ij}^1 - x_{ij}) f(x_{ij}) dx_{ij} \right] + \sum_{i=1}^N \sum_{j=1}^3 P_{ij}^1 \left[\int_{R_{ij}^1}^\infty (x_{ij} - R_{ij}^1) f(x_{ij}) dx_{ij} \right] \end{aligned} \quad (15)$$

where $\Phi(x)$ is the standard normal distribution function, $G(x) = \int_{-\infty}^x t\varphi(t) dt < 0$, and $\varphi(t)$ is the standard normal

density function.

1.3 Two-echelon model

Suppose that there are also N hospitals and $f(x)$ represents the PDF of review period demand. Let x_{ij} and x_c represent review period demand for department j in hospital i and the TPL service center, respectively. Let H_{ij}^2 and H_c represent unit-holding cost for department j in hospital i and the TPL service center, respectively. Suppose that P_c represents unit penalty (backorder) cost for the TPL service center. In modeling the problem, it is necessary to enhance the backorder costs in order to maintain service level. If the total emergency deliveries to a hospital (reflected in total backorders) exceeded a constant m_i unit, it would charge a higher penalty cost per unit of P while backorders within this limit would incur a penalty cost of P_{ij}^2 . It is necessary to incorporate a set of additional 0-1 decision variables y_i in our model to capture such effects. $y_i = 1$ if backorders do not exceed m_i ; $y_i = 0$, otherwise. In this model, the decision variables are R_{ij}^2 and R_c , which represent the par levels for each department and the TPL service central warehouse, respectively. As we have done in the three-echelon model, the department par levels are determined to ensure that a minimum pre-specified service level δ_{ij} for each department j in hospital i is maintained. Thus, the par level R_{ij}^2 for each department j in hospital i is determined such that it is associated with service level β_{ij}^2 which is at least as large as the minimum pre-specified service level δ_{ij} . Similarly, the model on the premise of a review period is presented as follows:

$$\begin{aligned} \min C_{E,2}(R_c, R_{ij}^2, y_i) = & H_c \left[\int_0^{R_c} (R_c - x_c) f(x_c) dx_c \right] + P_c \left[\int_{R_c}^{\infty} (x_c - R_c) f(x_c) dx_c \right] + \\ & \sum_{i=1}^N \sum_{j=1}^3 H_{ij}^2 \left[\int_0^{R_{ij}^2} (R_{ij}^2 - x_{ij}) f(x_{ij}) dx_{ij} \right] + \sum_{i=1}^N (1 - y_i) \left\{ P_{ij}^2 m_i + P \left[\sum_{j=1}^3 \int_{R_{ij}^2}^{\infty} (x_{ij} - R_{ij}^2) f(x_{ij}) dx_{ij} - m_i \right] \right\} + \\ & \sum_{i=1}^N \sum_{j=1}^3 y_i P_{ij}^2 \left[\int_{R_{ij}^2}^{\infty} (x_{ij} - R_{ij}^2) f(x_{ij}) dx_{ij} \right] \end{aligned} \quad (16)$$

such that

$$\int_{R_{ij}^2}^{\infty} (x_{ij} - R_{ij}^2) f(x_{ij}) dx_{ij} - (1 - \beta_{ij}^2) \mu_{ij}^2 \leq 0 \quad i = 1, 2, \dots, N; j = 1, 2, 3 \quad (17)$$

$$R_c - \sum_{i=1}^N \sum_{j=1}^2 \left[R_{ij}^2 - \int_0^{R_{ij}^2} (R_{ij}^2 - x_{ij}) f(x_{ij}) dx_{ij} \right] \geq 0 \quad (18)$$

$$\sum_{j=1}^3 \int_{R_{ij}^2}^{\infty} (x_{ij} - R_{ij}^2) f(x_{ij}) dx_{ij} - m_i \leq (1 - y_i) M \quad i = 1, 2, \dots, N \quad (19)$$

$$\left[\sum_{j=1}^3 \int_{R_{ij}^2}^{\infty} (x_{ij} - R_{ij}^2) f(x_{ij}) dx_{ij} - m_i \right] (1 - y_i) \geq 0 \quad i = 1, 2, \dots, N \quad (20)$$

$$\beta_{ij}^2 \geq \delta_{ij} \quad (21)$$

$$y_i = \{0, 1\} \quad i = 1, 2, \dots, N \quad (22)$$

$$R_c, R_{ij}^2 \geq 0 \quad i = 1, 2, \dots, N; j = 1, 2, 3 \quad (23)$$

The objective function sums up the holding costs based on expected inventory levels at two echelons (the TPL service center and departments within each hospital) and also assesses a penalty cost for expected backorders for all echelons within each hospital (see Eq. (16)). If $y_i = 0$, then total backorders for all departments within a hospital exceed m_i , and hence the penalty costs P_{ij}^2 (to the first m_i units) and P (for the excess units) are charged while if $y_i = 1$, then only the penalty costs P_{ij}^2 are charged per unit. As for the three-echelon model, constraint (17) is the relationship between the expected demand satisfied and the inventory for department j in hospital i based on service level β_{ij}^2 . Constraint (18) captures the fact that service center inventories must be adequate to satisfy the expected replenishments for all departments in all hospitals. Based on constraints (19) and (20), y_i is limited to the appropriate value of 0 or 1, and M is a sufficiently "large" constant. Obviously, β_{ij}^2 is constrained to be at least as large as δ_{ij} which is the pre-specified minimum service level that should be maintained for the department (see constraint (21)). Finally, the binary and non-negativity constraints on decision variables are incorporated in constraints (22) and (23).

Because of the high demand for the collaborative fellowship of supply chains in the realization of the two-echelon medicine inventory model, it is convincing that there is a fixed replenishment lead-time L_0 between the supplier and the TPL service center in the two-echelon network system. In other words, because of the collaborative fellow-

ship of the supply chain, suppliers have to provide needed medicine to the TPL service center in a certain time L_0 . According to the model of Ref. [7], $\mu_{ij}(L_0)$ is assumed the mean demand for department j in hospital i with fixed lead-time L_0 , $\mu_{ij}(L_0) = L_0\mu_{ij}$. Also, $V_{ij}(L_0)$ is assumed the standard deviation of demand for department j in hospital i with fixed lead-time L_0 , $V_{ij}(L_0) = L_0\sigma_{ij}^2$. Then the demand of the TPL service center with fixed lead-time L_0 obeys $N(L_0\mu_{ij}, L_0\sigma_{ij}^2)$.

In the same way, according to Ref. [9], the maximum medicine inventory of service central warehouse is $R_c = L_0\mu_{ij} + c\sqrt{L_0\sigma_{ij}^2}$, where c represents a safe factor for the service central warehouse in the two-echelon model. Integrating R_c and formula (16), and then standardizing the demand, it is concluded that

$$C_{E,2}(R_c, R_{ij}^2, y_i) = [(H_c + P_c)c\Phi(c) - (H_c + P_c)G(c) - P_c c] \sqrt{L_0\sigma_{ij}^2} + \sum_{i=1}^N \sum_{j=1}^3 H_{ij}^2 \left[\int_0^{R_{ij}^2} (R_{ij}^2 - x_{ij})f(x_{ij})dx_{ij} \right] + \sum_{i=1}^N (1 - y_i) \left\{ P_{ij}^2 m_i + P \left[\sum_{j=1}^3 \int_{R_{ij}^2}^{\infty} (x_{ij} - R_{ij}^2)f(x_{ij})dx_{ij} - m_i \right] \right\} + \sum_{i=1}^N \sum_{j=1}^3 y_i P_{ij}^2 \left[\int_{R_{ij}^2}^{\infty} (x_{ij} - R_{ij}^2)f(x_{ij})dx_{ij} \right] \quad (24)$$

As shown in Eqs. (15) and (24), with the increase of mean and deviation of lead-time, the maximum inventory level R_w, R_i, R_c and the total cost $C_{E,1}, C_{E,2}$ are becoming higher. It shows that the variety of stochastic lead-time has a very important effect on inventory level. Therefore, lead-time should be a consideration factor in the optimization of inventory costs. By using Matlab software, the variety is shown in Fig. 1 and Fig. 2.

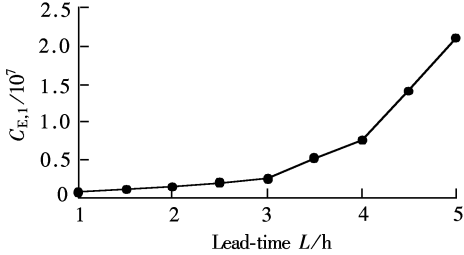


Fig.1 Stochastic lead-time and three-echelon inventory

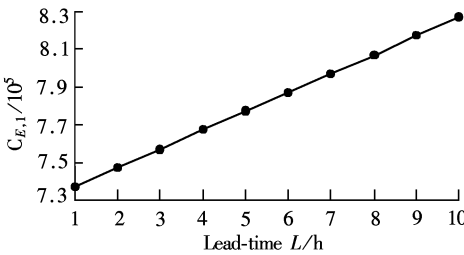


Fig.2 Fixed lead-time and two-echelon inventory

2 Numerical Simulation and Sensitivity Analysis

Let $\mu_{ij} = 100, \sigma_{ij} = 30, N = 10, H_w = H_c = 4.9, P_w = P_c = 75, H_i = 7, P_i = 107, H_{ij}^1 = H_{ij}^2 = 10, P_{ij}^1 = P_{ij}^2 = 153, m_i = 20, P = 300, L_0 = 2, \delta_{ij} = 90\%$. Using the Lingo software to simulate the two models, we get the results in Tab. 1 and Tab. 2.

Tab.1 Numerical simulation of three-echelon model

Three-echelon model	Unit holding cost	Unit penalty (backorder) cost	Demand with replenishment lead-time	Optimal inventory level and cost
Central warehouse	4.9	75	$E(T_{s,w}D) = 18\ 265, V(T_{s,w}D) = 66\ 351$	$R_w = 120\ 693.2, C_w = 642\ 419.8$
Hospital i warehouse	7	107	$E(T_{s,i}D) = 93\ 061, V(T_{s,i}D) = 27\ 355$	$R_i = 51\ 517.45, C_i = 378\ 260.6$
Department j warehouse in hospital i	10	153	$\mu_{ij} = 100, \sigma_{ij} = 30$	$R_{ij}^1 = 146.306\ 3, C_{ij}^1 = 592.735\ 5$
Total inventory cost	1 021 273.136			

Tab.2 Numerical simulation of two-echelon model

Two-echelon model	Unit holding cost	Unit penalty (backorder) cost	Demand with replenishment lead-time	Optimal inventory level and cost
TPL central warehouse	4.9	75	$\mu_c(L_0) = 4\ 000, V_c(L_0) = 36\ 000$	$R_c = 67\ 567.51, C_c = 711\ 282.6$
Department j warehouse in hospital i	10	153	$\mu_{ij}(L_0) = 200, V_{ij}(L_0) = 1\ 800$	$R_{ij}^2 = 2\ 978.375, C_{ij}^2 = 35\ 564.13$
Total inventory cost	746 846.73			

Compared to the three-echelon network structure, it is shown that the two-echelon model not only keeps the service level high but also obviously reduces the inventory level from 1 021 273.136 to 746 846.73. Moreover, we only consider the single non-critical item and an arborescent multi-echelon distribution system in this paper. If the improvement is extended to multi-item and multi-arborescent, it is convincing that these savings would obviously be larger.

3 Conclusion

By considering the positive replenishment lead-time, we modify the modes in Ref. [3]. Comprehensive lists in presenting both models are given in Tab. 1 and Tab. 2, respectively. It is illustrated that the two-echelon model obviously not only keeps the service level but also reduces the inventory cost when compared to the three-echelon network structure. It really realizes a true “win-win” situation. However, both models have some shortcomings. For example, the demand for the single item is assumed to be independent across hospitals and across departments within a hospital in our models. But the fact is that the demand of a single item may be correlated across departments within a hospital or departments across hospitals. This would require the formulation of more complicated cost functions reflecting joint probability density functions of item demands as well as constraints where the service levels are also jointly determined. In addition, the influence of different character lead-times on the total inventory costs will also be given further research in the area of distribution systems within the healthcare industry.

References

- [1] Prashant N D. A systematic approach to optimization of inventory management functions[J]. *Hospital Material Management Quarterly*, 1991, **12**(4): 34 – 38.
- [2] Lunn T. Ways to reduce inventory [J]. *Hospital Material Management Quarterly*, 2000, **21**(4): 1 – 7.
- [3] Nicholson L, Vakharia A J, Erenguc S S. Outsourcing inventory management decisions in healthcare: models and application [J]. *European Journal of Operational Research*, 2004, **154**(1): 271 – 290.
- [4] Williams C L, Patuwo B E. A perishable inventory model with positive order lead times [J]. *European Journal of Operational Research*, 1999, **116**(2): 352 – 373.
- [5] Liu Liming, Yang Tao. An (s, S) random lifetime inventory model with a positive lead time [J]. *European Journal of Operational Research*, 1999, **113**(1): 52 – 63.
- [6] Bookbinder J H, Cakanyildirim M. Random lead times and expedited orders in (Q, r) inventory systems [J]. *European Journal of Operational Research*, 1999, **115**(2): 300 – 313.
- [7] Zhang Chunxiao, Xie Jinxing. Optimization of a two-level distribution inventory system with random lead-time and stochastic demand progress [J]. *Mathematics in Practice and Theory*, 2004, **34**(7): 1 – 8. (in Chinese)
- [8] Ma Shihua, Lin Yong. An inventory model based on stochastic lead time [J]. *Computer Integrated Manufacturing Systems*, 2002, **8**(5): 396 – 398. (in Chinese)
- [9] Liu Jian, Ma Shihua. Research on model of supply chain inventory coordination and optimization [J]. *Journal of Management Sciences*, 2004, **7**(4): 1 – 8. (in Chinese)

具有提前期的三级和二级药品库存模型比较

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摘要:根据总成本最小原则,在考虑需求提前期影响的情况下,建立了基于随机提前期的三级药品库存优化模型和基于常值提前期的二级药品库存优化模型.运用 Matlab 软件研究了提前期与库存成本的关系,说明了提前期的变化对药品库存系统有着重要的影响.通过数据实例借助 Lingo 软件对 2 个模型进行了仿真计算和比较,结果表明,在保证服务水平的前提下,具有提前期的二级药品库存的总成本比三级药品库存的总成本有明显降低.

关键词:医疗供应链;库存管理;提前期;优化模型

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