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Arena Simulation of Multi-Level Medicine Inventory Control In Hospital Pharmacy

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Abstract

Precise control of hospital pharmacy inventory is an important guarantee for hospital. The optimal inventory policy for a multi-level medicine inventory control in hospital pharmacy was considered in this paper, and modeling simulation technology and intelligent optimization has been used. Analyzed with large-scale hospitals data, this paper has discussed the following problems: random fluctuations of demand in hospital departments, total volume limits and uncertainty response time of suppliers' delivery. Establish multilevel pharmaceutical inventory simulation model, then use PSO method for intelligent optimization. Examples of simulation models and PSO algorithms verified by numerical results show that: when each department was tested randomly varying demand of the patients, multi-level inventory management must be overall coordination in order to achieve optimum system.

Keywords: *hospital pharmacy; multi-level inventory; ARENA; PSO*

1. Introduction

In recent years, a medical and health system reform has been carried out from national level, forcing the upgrading and innovation of pharmacy administration in many hospitals and pharmaceutical trading enterprises to protect public medication safety and proper cost. The multi-level medicine inventory control in hospital refers to the collection, processing, distribution and storage of various medicine and the operation of this inventory control (like accuracy, efficiency and cost) has direct influence on the medical service level of hospitals. The existing operation model of medicine inventory control in hospital has the problem of low efficiency, large inventory, redundant management process, serious human resources bottleneck, which leads to more and more serious problems like medicine expiry and occupation of funds. Under this new situation, it is imperative for us to optimize medicine inventory control model. EL Nichols was first defined the pharmaceutical supply chain (PSC). Pharmaceutical Supply Chain (PSC) can be defined as "the integration of all activities associated with the flow and transformation of drugs from raw materials through to the end user, as well as associated information flows, through improved supply chain relationships to achieve a sustainable competitive advantage".

In China, hospital has the right to purchasing and operate medicines for own using. According to the statistics from China's pharmaceutical industry association: in Chinese general hospital, pharmaceutical sales revenue of is often much more than 40% of total revenue. Although the mode of "Drug dependent doctors" in China is unreasonable, however, it is difficult to eliminate in the short term. To common sense, the important thing should be continuously optimized by hospital management. It is ironic that China hospitals are not doing so. While pharmaceutical supply chain has very important implications for hospitals, its

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efficiency is very low. Due to the long opaque management and operation, resulting in the hospital's pharmaceutical supply chain structure is very complicated.

The research of medicine inventory control in hospital by scholars home and abroad is limited in the aspects of bottleneck analysis of medicine inventory control, medicine inventory control under the condition of deterministic demand and optimization of medicine storage condition, like adopting modified ABC analysis method to determine medicine classification; adopting periodic and quantitative ordering method to control the level of inventory; rationally setting upper and lower limit of medicine inventory. This kind of research generally puts forward countermeasures against the control problems encountered in practice and thus it is reality-oriented. However, the research is lacking in theoretical depth and the results don't have generality. Fruitful achievements have been gained since the proposal of multi-level medicine inventory control. Speaking from research technical route, there are mainly two types of routes: one is analytical method. In this method, analysis is conducted by adopting mathematical modeling and relative analytical tools, mainly divided into consecutive requirement model and discrete requirement model; the second is simulation method. Considering problems existing in mathematical modeling applying analytical method, like big difficulty, too many assumed conditions, difficulty in finding solution, it is very hard to implement. Simulation method carries out simulation of real situation by using relative software and then draws the conclusion of system operation. That is to say, it can complete the analysis process without conducting complex system modeling. However, the simulation method still has the problems of inaccurate simulation modeling, unstable operation results and difficulty in finding optimization. This paper establishes simulation modeling making use of Arena and applies PSO method to optimize medicine inventory decision, which gives consideration to the characteristics of simulation efficiency and optimization intelligence and has referential significance for future study.

2. Problem Description and Mathematical Modeling

2.1. Problem Description

The multi-level medicine inventory control system in hospital is made up of several drug dealers (distributors) S, a hospital level drug storehouse PDC, several division pharmacies DC, several departments W and several patients P. Each department needs to satisfy the random drug demand of different patients: based on medical order, the head nurse collects the demand for conventional drug of each patient (the third grade drug storeroom of each department is equipped with first-aid medicine, which adopts cardinal number of drug control model and will not be discussed in this paper). Every morning, each department sends the demand order to the division pharmacy DC that they belong to and the division pharmacy DC directly delivers the drug to the department after picking. When there is unbalance between supply and demand in the division pharmacy DC, it will send replenishment requirement to hospital level drug storehouse PDC; delivery will be arranged considering the work load and operational ability of PDC. The hospital level drug storehouse PDC sends order request to the upstream drug supplier and receives the delivery of supplier. The multi-level medicine inventory control system in hospital is shown in Figure 1.

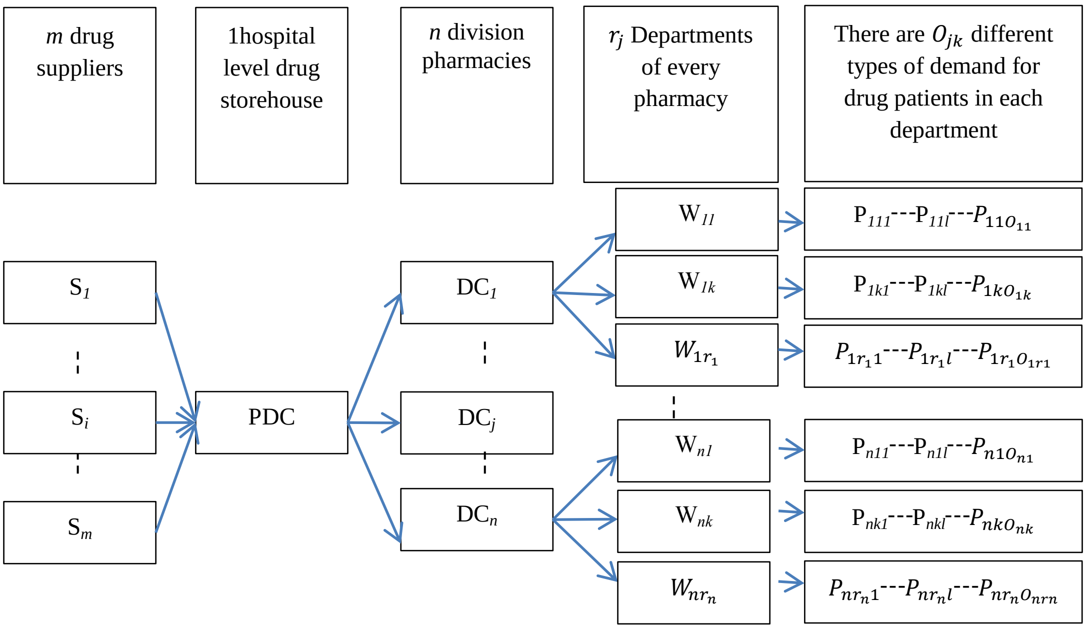

Figure 1. Structure of Multi-Level Medicine Inventory Control System

2.2. Model Assumption

To preserve generality and typicality, we make the following critical assumptions:

(1) No allowance of stock out in the system;

(2) To simplify the difficulty of modeling, we shall combine similar demands of patients and abstract as several typical distributions;

(3) Mutual independence between the drug demand of each patient and department;

(4) Each order demand can be satisfied by one supplier or several suppliers;

(5) Combine the drug as single kind of drug according to the demand conditions and delivery scale;

(6) Assume that the delivery center can deliver the drug after receiving the order demand of each division pharmacy and the time of delivery is consistent.

2.3. Symbolic Meaning

S_i represents the *i* th drug supplier, $i=1,2,3\cdots\cdots,m$；PDC represents the distribution center of hospital drug; DC_j represents the *j* division pharmacy, $j=1,2,3\cdots\cdots n$; W_{jk} represents the *k* department served by the *j* division storeroom, $j=1,2\cdots\cdots,n$；$k=1,2\cdots\cdots,r_j$; P_{jkl} represents the *l* patient in the *jk* department, $l=1,2,\cdots\cdots,O_{jk}$.

Let $RQP_{jkl}(t)$ represents the drug demand of the *jkl* patient at the end of *t* period; $RQW_{jk}(t)$ represents the drug demand of *jk* department at the end of t period, $RQ_j(t)$ *is* the total amount of drug demand in all service departments of j division pharmacies at the end of *t* period, $RQ(t)$ represents the total amount of drug demand of all patients in hospital at the end of t period. Let $\mathrm{IQ}_j(t)$ represents the drug inventory of the *j* division at the end of *t* period, $OQ_j(t)$ represents the order quantity of the *j* division at the end of *t* period, TOQ(t) represents the total order quantity received by PDC at the end of *t* period. Let $IQ_{PDC}(t)$ represents the inventory of PDC at the end of *t* period, $\overline{IQ_{\mathrm{pdc}}(t)}$ represents the average inventory of PDC during *t* period; TRQ(t) represents the total demand of patients at *t* moment, $EOQ_{PDC}(t)$ represents the emergency order quantity of PDC at the end of *t* moment, $NOQ_{PDC}(t)$ represents the conventional order quantity of PDC at *t* moment. Let

N_E represents the frequency of emergency ordering by the PDC, N_N represents the frequency of conventional ordering by the PDC.

The cost of medicine inventory control in hospital is made up of three parts: the order distribution of each link, ordering cost and inventory holding cost. The meaning of relative symbols in objective functions is as follow:

(1) Inventory cost related to the PDC: C_{1E} represents the unit delivery cost generated by PDC emergency ordering (Yuan/Unit), C_{1N} represents the unit delivery cost generated by PDC conventional ordering (Yuan/Unit); C_{2E} represents the single emergency ordering cost of PDC (Yuan/Unit), C_{2N} represents the single conventional ordering cost of PDC (Yuan/Unit); C_3 represents the unit drug inventory holding cost (Yuan/Unit). DCE_{pdc} represents the PDC delivery cost of emergency ordering, DCN_{pdc} represents the PDC delivery cost of conventional ordering; OCE_{pdc} represents the PDC emergency ordering cost, OCN_{pdc} represents the PDC conventional ordering cost; IC_{pdc} represents the PDC inventory holding cost.

(2) The inventory cost related to each division pharmacy: C_4 represents the unit delivery cost generated by ordering of each division pharmacy (Yuan/Unit), C_5 represents the single ordering cost of each division pharmacy (Yuan/Time), C_6 represents the unit drug inventory holding cost of each division pharmacy (Yuan/Unit. year). DC_j is represents the ordering delivery cost of the pharmacy in j division, OC_j represents the ordering cost of the j division pharmacy, IC_j represents the inventory holding cost of the j division pharmacy. TC represents the annual total cost of hospital drug inventory management.

2.4. Basic Relation

The total drug demand of all patients equals to the drug demand of the department and total drug demand of all departments equals to the drug demand of the division pharmacy, which satisfy:

$$RQ_{jk}(t) = \sum_{l=1}^{O_{jk}} RQ_{jkl}(t) \tag{1}$$

$$RQ_j(t) = \sum_{k=1}^{r_j} RQ_{jk}(t) \tag{2}$$

$$RQ(t) = \sum_{j=1}^{n} RQ_j(t) = \sum_{j=1}^{n} \sum_{k=1}^{r_j} \sum_{l=1}^{Q_{jk}} RQ_{jkl}(t) \tag{3}$$

$$IQ_j(\mathrm{t}+1) = IQ_j(\mathrm{t}) - RQ_j(\mathrm{t}) \tag{4}$$

Considering there can be no allowance of stock out in division pharmacy DC, which is $IQ_j(\mathrm{t}) > 0$. Therefore, the medicine inventory control model of division pharmacy DC is (SS, QMAX) : Check the inventory level of every division pharmacy on a regular basis (like 1d). When the inventory level is below the security cordon SS_j, system will send ordering command and replenish the drug to $QMAX_j(\mathrm{t})$. Let $U_j(\mathrm{t})$ represents whether the j th division pharmacy has made the ordering demand or not at the end of moment t, then we have:

$$U_j(\mathrm{t}) = \begin{cases} 1 & IQ_j(\mathrm{t}) \le SS_{(\mathrm{j})} \quad \text{Need order} \\ 0 & IQ_j(\mathrm{t}) > SS_{(\mathrm{j})} \quad Don't\ need\ order \end{cases} \tag{5}$$

The delivery times of PDC at the end of moment t: $\mathrm{D}N_{(\mathrm{t})} = \sum_{j=1}^{n} U_j(\mathrm{t})$, the delivery quantity of PDC:$\mathrm{DQ(t)} = QMAX_j(\mathrm{t}) - IQ_j(\mathrm{t})$, after the delivery, the inventory level restores to the maximum level of division pharmacy $QMAX_j(\mathrm{t})$.

The real-time ordering and receiving with upstream drug dealers can only adopt the form of fixed ordering cycle, namely the model of$(\mathrm{T,S})$: check the inventory on a regular basis (usually every week) and then determine the ordering quantity according to the estimated quantity demanded $QMAX_{PDC}$ based on the remaining inventory and experience to restore the inventory level. Assume that the ordering is made at the end of every week to satisfy the ordering demand of all division pharmacies in this week. The purchase quantity of PDC in week α: $\mathrm{PQ}(\alpha) = S_{PDC} - IQ_{PDC}(\alpha)$. After receiving the ordering demand of hospital PDC, the replenishment of PDC center is jointly carried out by m drug suppliers. Assuming that $DS_i(\alpha)$ represents the PDC replenishment quantity of the i th supplier at the end of week, to prevent the stock out, we have the requirement:

$$\sum_{i=1}^{m} DS_i(\alpha) \geq \mathrm{PQ}(\alpha) \quad (6)$$

2.5. System Target

The target of inventory control model is: no allowance of stock out and achieve the minimization of total average inventory quantity and total cost in medicine inventory control system. The hospital PDC center inventory cost includes three parts:

1) total ordering delivery cost: $\mathrm{DC_{pdc}} = \mathrm{DCE_{pdc}} + \mathrm{DCN_{pdc}} = \mathrm{C_{1E}} * \sum_{t=1}^{365} \mathrm{EOQ_{PDC}(t)} + \mathrm{C_{1N}} * \sum_{t=1}^{365} \mathrm{NOQ_{PDC}(t)}$;

2) total ordering cost: $\mathrm{OC_{pdc}} = \mathrm{OCE_{pdc}} + \mathrm{OCN_{pdc}} = \mathrm{C_{2E}} * \mathrm{N_E} + \mathrm{C_{2N}} * \mathrm{N_N}$;

3) total inventory holding cost: $\mathrm{IC_{pdc}} = \mathrm{C_3} * \overline{\mathrm{IQ_{pdc}(t)}}$

The j th division pharmacy inventory cost includes three parts:

1) delivery cost: $\mathrm{DC_j} = \mathrm{C_4} \times \sum_{t=1}^{365} \mathrm{OQ_j(t)}$;

2) ordering cost: $\mathrm{OC_j} = \mathrm{C_5} \times \sum_{j=1}^{n} \sum_{t=1}^{365} \mathrm{U_j(t)}$;

3) inventory holding cost: $\mathrm{IC_j} = \mathrm{C_6} \times \overline{\mathrm{IQ_j(t)}}$.

The annual total cost of hospital medicine inventory control is as follow:

$$\mathrm{TC} = \mathrm{DC_{pdc}} + \mathrm{OC_{pdc}} + \mathrm{IC_{pdc}} + \sum_{j=1}^{n}\left(\mathrm{DC_j} + \mathrm{OC_j} + \mathrm{IC_j}\right) \quad (7)$$

3. Problem Solving

In the target function of above-mentioned model, the drug demand of every patient $\mathrm{RQ_{jkl}(t)}$ is random fluctuation function bearing the characteristics of periodic change and the multiple random superposition leads to the great uncertainty of demand. It is very difficult to find the solution using analytical method. Moreover, we must make assumption about real data on a large scale, and thus the result we get will undoubtedly far apart from real situation. To solve this problem efficiently, we can adopt simulation optimization design method, which is much easier to implement. This paper adopts the discrete simulation software ARENA13.5 to establish simulation mathematical modeling of the medicine inventory control of hospital pharmacy, conducts multiple repeated tests, finds the drug demand distribution function and applies the particle swarm optimization, namely the PSO method to conduct optimization.

Basic principle of PSO method: in the N-dimensional space, the population $\mathrm{X} = \{x_1, x_2, x_i, \cdots, x_i\}$ is composed by n particles, among which $x_i = \left\{x_{i1}, x_{i2}, x_{ij}, \cdots, x_{in}\right\}^T$ represents the position of particle, $V_i = \left\{V_{i1}, V_{i2}, V_{ij}, \cdots, V_{in}\right\}^T$ represents the speed of particle, $P_i = \left\{P_{i1}, P_{i2}, P_{ij}, \cdots, P_{in}\right\}^T$ represents the individual extremes of particle and $P_g = \left\{P_{g1}, P_{g2}, P_{gi}, \cdots, P_{gn}\right\}^T$ represents the global extremes. According to the PSO optimization principle, the formula is as follow:

$$V_i(t+1) = \omega * V_i(t) + c_1 * r_1 * [P_i(t) - X_i(t)] + c_2 * r_2 * [P_m(t) - X_i(t)] \quad (8)$$

$$X_i(t+1) = X_i(t) + V_i(t+1) \quad (9)$$

$V_i(t)$ represents the speed of particle i at t moment, ω represents the weighted value of inertia, $X_i(t)$ represents the position of particle i at t moment, $r_1 \in (0,1)$、$r_2 \in (0,1)$. Both of which are mutually independent random parameters. In this paper, $c_1 = c_2 = 2$.

The optimization procedures are:

1) Determine the scale of particle swarm N and then conduct initialization;

2) Determine the adaptive value of each particle,

3) Compare the adaptive value of each particle with the optimal value of adaptive value in the previous step: if it is superior to the previous step, then regard it as the local optimum at present; if it is inferior to the previous step, then retain the original local optimum;

4) Compare the adaptive value of each particle with the global optimum of all particles: if it is superior to the previous step, then regard it as the global optimum at present; if it is inferior to the previous step, then retain the original global optimum;

5) Update the position and speed of the particle based on formula (9) and (10);

6) Judge whether we can obtain the optimum or not based on the terminal conditions set before: if obtain, stop the iteration and output results; if not, return to the second procedure and repeat the iteration.

4. Analysis of Examples

4.1. Original Data Acquisition and Processing

To further know about the main bottleneck of the medicine inventory control in hospital, this paper conducts observation in the Second Xiangya Hospital, Central South University through the form of granting questionnaires, observation statistics and interview investigation. The researchers issued 239 questionnaires, 227 questionnaires, 211 valid questionnaires, and the requirements of the questionnaires were collected. The existing medicine inventory model in hospital is shown in Figure 2.

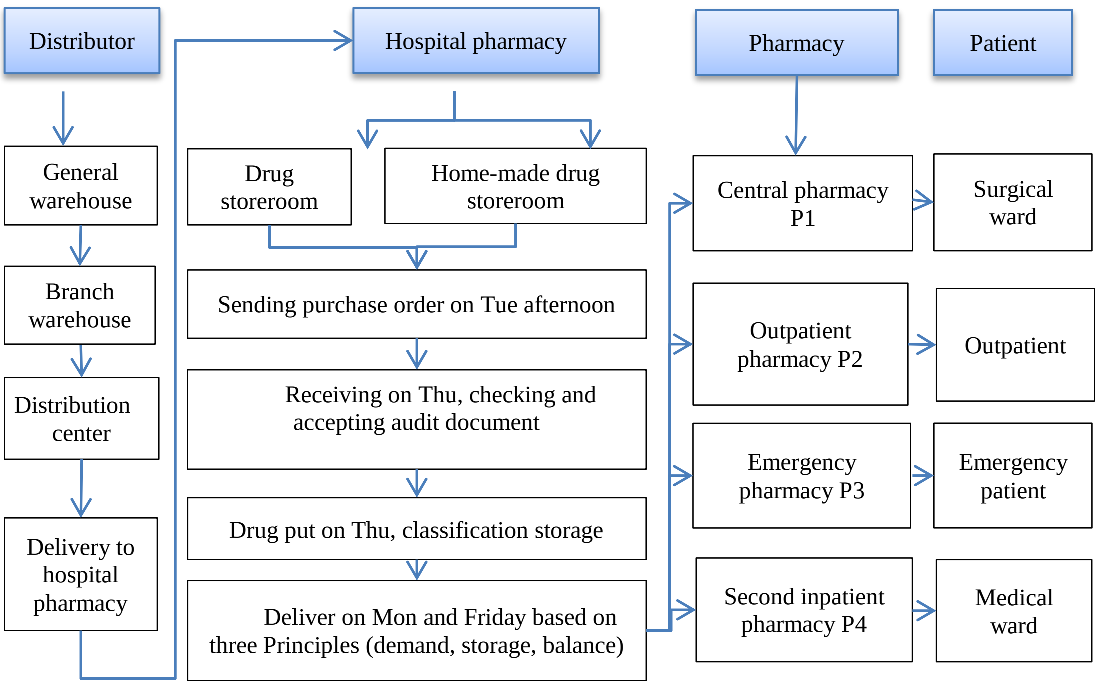

Figure 2. Existing Medicine Inventory Operation Model of the Second Xiangya Hospital

The common drugs in the the Second Xiangya Hospital include 12 major categories of more than 1500 kinds and the purchase and selling frequency and number is different from one another. The related data distribution function is shown in Table 1, the related cost data is shown in Table 2 and the constraint on storage capacity is shown in Table 3.

Table 1 Demand Data of Hospital Medicine Multi-level Inventory

S_i	PDC	DC_j	W_{jk}	Demand distribution
S_1-S_{10} m = 10	(T, Q)	DC_1	W_{11}	P_{111}~PIOS(20), 8p/d; P_{112}~PIOS(102),9p/d; P_{113}~EXPO(8),21p/d; P_{114}~NORM(160,38),16p/d;
			W_{12}	P_{121}~NORM(50,3.2),7p/d; P_{122}~EXPO(34),24p/d
			W_{13}	P_{131}~PIOS(18), 11p/d; P_{132}~BETA(42,11),17p/d; P_{133}~EXPO(43),8p/d;P_{134}~NORM(23,1.8),16p/d;
			W_{14}	P_{141}~PIOS(145), 28p/d; P_{142}~EXPO(28),6p/d;
			W_{15}	P_{151}~PIOS(32), 9p/d; P_{152}~BETA(37,6),23p/d;
			W_{16}	P_{161}~EXPO(34),42p/d; P_{162}~NORM(45,2.9),21p/d;
			W_{17}	P_{171}~PIOS(28), 15p/d; P_{172}~BETA(32,6),13p/d; P_{173}~EXPO(41),4p/d;
			W_{18}	P_{181}~NORM(55,4),43p/d;
			W_{19}	P_{191}~PIOS(45), 8p/d; P_{192}~BETA(42,11),7p/d; P_{193}~PIOS(18), 11p/d;
		DC_2	W_{21}	P_{211}~PIOS(18), 11p/d; P_{132}~NORM(35,1.7)23p/d;
			W_{22}	P_{221}~NORM(45,13),26p/d;
		DC_3	W_{31}	P_{311}~NORM(51,7.2),37p/d ; P_{312}~NORM(42,6.8),5p/d
			W_{32}	P_{321}~PIOS(48), 9p/d; P_{322}~NORM(45,2.9),28p/d;
			W_{33}	P_{331}~NORM(32,1.9),52p/d; P_{332}~PIOS(18), 13p/d
			W_{34}	P_{341}~PIOS(33), 9p/d;P_{342}~PIOS(45),22p/d; P_{343}~BETA(35,6),17p/d;
			W_{35}	P_{351}~PIOS(23), 6p/d; P_{352}~BETA(42,11),5p/d; P_{353}~NORM(45,3),9p/d;
			W_{36}	P_{361}~NORM(45,2.9),21p/d; P_{362}~POIS(38),23p/d;
		DC_4	W_{41}	P_{411}~EXPO(23),7p/d;P_{412}~NORM(53,5),9p/d;P_{413}~EXPO(35),8p/d; P_{414}~NORM(37,1.5),21p/d; P_{415}~BETA(34,8),12p/d

Table 2. Related Cost Data of Hospital Medicine Multi-level Inventory Control

Variable	C_{1E}	C_{1N}	C_{2E}	C_{2N}	C_3	C_4	C_5	C_6
Cost parameter	3	1	25	10	0.5	2	20	0.6

Table 3. Constraint Data of Hospital Medicine Multi-level Storage Capacity

Variable	$QMAX_1$	$QMAX_2$	$QMAX_3$	$QMAX_4$	$QMAX_{PDC}$
Constraint	100000	30000	120000	30000	500000

4.2. Establishing Simulation Model

This paper analyzes every element in the medicine inventory system and builds different function bodies; sets different variable function formulas according to the variable statistical rule, like drug inventory, delivery times, delivery quantity; sets service resource quantity based on the service capability of every node in the process. The simulation model built is shown in Figure 2.

4.3. Simulation Experiment and the Analysis of its Result

The simulation experiment of the simulation model in Figure2 is conducted on the platform of Intel Core i5and 4G memory. The single simulation unit time length is 365 days and the experiment is repeatedly conducted 20 times to calculate related results. Moreover, PSO method is adopted to carry out the optimization addressing calculation. It takes about 1 hour to conduct the simulation experiment, basically satisfying the actual demand. The optimization result is shown in Table 4.

Table 4. Satisfactory Solution Acquired by PSO Optimization

Variable	*Value*	*Actual value*	*Cost variable*	*Numerical value*	*COST*
$QMAX_1$	2.23RQ1	33789.63	EOQPDC	771.83	2315.48
$QMAX_2$	2.31RQ2	5058.59	ENQPDC	27504.45	27504.45
$QMAX_3$	2.16RQ3	20264.62	NOE	241.00	6025.00
$QMAX_4$	2.19RQ4	3664.26	NON	50.00	500.00
$QMAX_{PDC}$	4.34RQPDC	129490.83	$\overline{IQPDC}$	79504.27	39752.14
SSQ1	1.14RQ1	17273.62	OQ_i	28282.20	56564.39
SSQ2	1.15RQ2	2518.35	NOQ_i	942.00	18840.00
SSQ3	1.18RQ3	11070.49	$\sum_{i=1}^{4} \overline{IQDC}_i$	53875.69	32325.42
SSQ4	1.15RQ4	1924.15			
SSQPDC	2.22RQPDC	63041.59	Total Cost of a year		183826.88

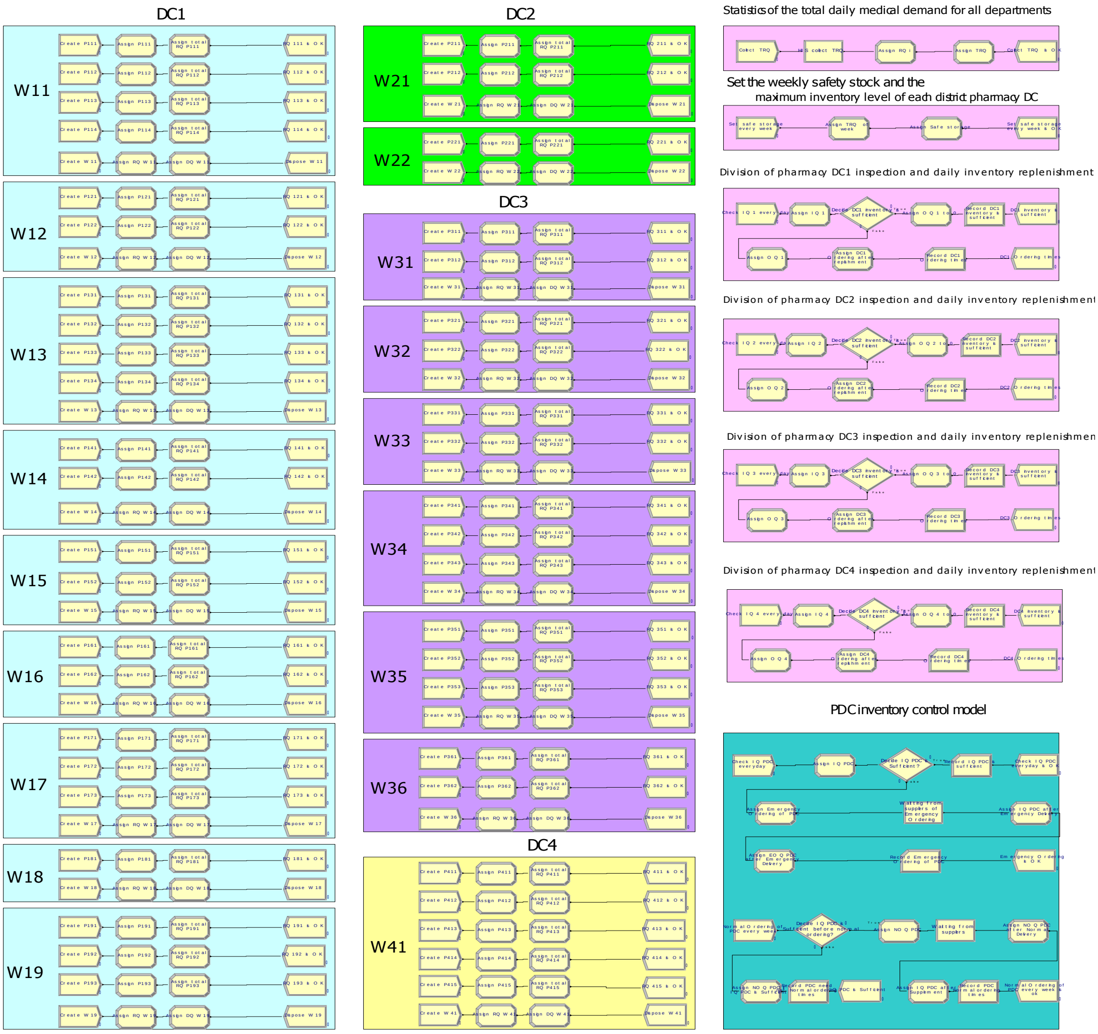

Figure 2. Simulation Model of Hospital Pharmacy Inventory in the Second Xiangya Hospital, Central South University

5. Research Conclusion

To solve the problem of large stock amount and high occupation of funds existing in the medicine inventory control in hospital, this paper finds the optimization solution by adopting Arena modeling and PSO method and obtains satisfaction solution for many times. The result of simulation experiment indicates that Arena modeling can significantly reduce the modeling difficulty of complicated discrete problems and the PSO optimization solution method bears the characteristics of fast convergence. The combination of two can efficiently solve the problem of multi-level inventory control. Considering the generality of model assumption, the result of this research can be applied solve the problem of multi-level inventory control in other fields.

In the future, the hospital medicine inventory management can be optimized from the demand of randomness, inventory capacity constraints, and other aspects of the emergency demand to change the assumptions, to achieve more realistic simulation and optimization. In the era of personalized medicine, the researchers need to consider the demand and supply of medicine in the hospital two-way dynamic adaptive configuration, in order to achieve the perfect match between medicine inventory management and real demand.

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