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Possibility of Inventory Pooling in China's public hospital and appraisal about its performance

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ABSTRACT

Aiming to problems of high drug shortage possibility and rupture of liquidity caused by serious liquidity occupied in drug supply chain of public hospitals in China, this paper discusses effectiveness about application of Inventory Pooling theory in this section. Employing Vensim software of system dynamic, the paper establishes 2 simulation models of whole process from drug demand to supply involved by patients, hospitals, distributors and manufacturers in traditional mode and the Pooling mode respectively. By quantitative comparison and analysis, it is proved that Inventory Pooling could be an effective method to improve performance of drug supply chain in China, especially in cutting down shortage possibility and reducing liquidity occupied.

1. Introduction

China has large population at about 1.3 billion, which shares 1/5 scale of world population. With reform of economy conducted in China in recent 30 years, reforms of medical care have been pushed by Chinese government. In China, most of public hospitals are owned by government, to see doctor in public hospital is a most ordinary choice of citizens as public hospitals have normally better medical technology and equipment compared with private hospitals. In 1994, Chinese government started its health care reform first from insurance and payment system in Jiujiang city of Jiangxi Province and Zhenjiang city of Jiangsu Province, which are typical 2 medium scale cities in China. In following decades of years, disputes on how to innovate on medical health have never ceased meanwhile exploration about it also never stop.

Among those disputes, Innovation about drug supply mode is a continuous hot topic. Innovation to centralize drug procurement in a province scope is aimed to reduce or eliminate opportunities of power renting seeking of public hospitals during their own procurement before and is expected to cut down procurement cost of drug. Now this innovation has been spread throughout whole country.

But the effect of this innovation is still limited at present. As per statistics of sample hospitals from Jiujiang city, Jiangxi Province aggregated procurement cost of drug in public hospitals was reduced by 4.2% after innovation. Compared with huge cost to run centralized procurement system, it is hard to say the innovation has succeeded.

Also, some apparent problems exist in present drug supply chain as per research in sample hospitals in Jiujiang of Jiangxi province, one of the earliest cities about medical innovation in china:

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0307-904X/

(1) Rupture of liquidity

Occupation of huge liquidity in the supply chain led to rupture of liquidity chain occasionally. After centralized procurement system employed, a manufacturer who win bidding may face drug supply to hospitals all over the province, which may bring good business but also led to drastic increment of liquidity demand.

(2) High drug shortage possibility.

As per investigation in sample hospitals, shortage ratio can reach 20% or so, the most serious situation can be 50%.

Above two problems could be caused by following reasons:

(1) Liquidity chain rupture caused by delaying supply from drug manufacturers to hospitals.
(2) Excessive amount order or less amount order often occurred. Most of hospitals are not good at logistics and supply chain management, which may incur high inventory level and large liquidity occupied or supply shortage respectively.
(3) Each entity such as hospital or distributor of drug supply chain just optimizes performance from view of its own instead of from whole supply chain. Local optimum is often not the overall best.

In order to solve above problems and make some improvement on KPI, a more professional and integrated mode of drug supply chain should take place of current mode.

As innovation of drug supply chain in China involves more than 1.3 billion citizen's care and health. Any change should be very cautious.

As per related theories, Inventory Pooling System (also named JMI – Joint Managed Inventory) applied to drug supply chain system may be a good attempt.

2. Literature overview

2.1. Overview about Pool System theory or JMI

The earliest notion about Inventory Pooling can be found in the literature of Eppen [1], in which Eppen analyzed the effects of centralization on expected costs in a multi-location newsboy problem. After that, thousands of papers have been making further research based on earlier conclusions.

Eppen and Schrage [2] included lead time as considered factor. Bannerjee [3] established optimized supplier-retailer jointly stock model which is constrained by limited production ratio based on objective function of minimum total cost between supplier and retailer. Goyal [4,5] and Hill [6] improved this model. Aiming to supply chain system of one warehouse and multi retailers, Goyal analyzed how strategy of Pooling System influenced it. Hill established a new Joint Production-Stock model under situation of single supplier – single retailer just two levels supply chain.

Alfaro and Charles [7] addressed the effect of non-optimal inventory policies and the effect of non-normally distributed demand on the value of Pooling. Yigal and He [8] proved correlation between the demand variability and the benefits after Pooling System applied circumstance.

Ben [9] research problem of Jointly Production-Stock model under stochastic demand and variable lead time.

Onyang [10] proposed the optimal inventory policy under normal distribution demand and demand whose distribution is undecided.

Wong [11] considered both non-zero lateral transshipment time and delayed lateral trans-shipments to estimate several performance measures in a single-item, multi-company and repairable inventory system.

Charles J. Corbett [12] confirmed centralization or Pooling of inventories is more valuable when demands are less positively dependent under multivariate stochastic order.

Dengfeng Wu [13] demonstrated how many safety stocks should be kept in centralized warehouse in order to meet normal distribution demands once Inventory Pooling runs.

From above literatures, we can know Pooling System can be a good theory and method to optimize supply chain with the theory development and its application in practice in past years. But actually almost few literatures can be found about Pooling System's application in hospital inventory control. The research of this paper will make an initial try based on empirical analysis and enrich its application scope.

The solution of Inventory Pooling for drug supply is designed as follows:

(1) Based on sharing information, distributors can centralize drug inventory kept in all hospitals in a region into a joint warehouse.
(2) Based on information exchange about daily demand, distributors implement frequent, small scale and lean distribution to hospitals in order to cut down inventory of whole supply chain and relieve pressure of liquidity occupied and reduce possibility of drug shortage caused by failure demand forecasting from hospitals like before.

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(3) The involved hospitals just keep minimum inventory in their own warehouses to respond to unexpected fluctuation in demand.

This paper is aimed to provide more apparent and intuitional analysis for decision making for department of authorities of China. It is necessary to compare about KPI before and after application of Inventory Pooling by simulation and quantitative analysis, which will be more effective and more persuasive. Thus related simulation models should be established and conducive.

Software development tool Vensim™ will be used to configure interrelationships of factors of drug supply chain. Vensim modeling language is a rich and readable way of representing dynamic systems and can provide a programming environment for model development and help solve problems that would be hard to address mathematically [14].

Here, accumulated liquidity occupied and shortage times are critical indicators to measure management level and health of drug supply chain, they will be listed as KPI in the paper for comparison and assess the effectiveness of employing Inventory Pooling.

3. Typical process of drug supply in public hospital currently

3.1. Current process of drug procurement

As per investigation from sample hospitals, typical replenishment method in China's public hospital is periodical replenishment with monthly frequency. The procurement department of the hospital starts its purchasing plan from calculating gross requirement, which is decided by daily demand forecasting and duration to be calculated. Normally the duration days here consist of actual purchasing cycle and some extra buffer days. Once gross requirement determined, net requirement can be decided, that is gross requirement minus drug inventory on hand and inventory in transition. Then hospital sends purchasing order to drug distributor periodically.

Distributor will make decision about order fulfillment, such as whether or how many drugs will be delivered to hospital, which is subjected to distributor's inventory level and situation of liquidity occupied by the hospital. Once deciding those, the distributor will ship out drug from its warehouse to meet hospital's requirement and also apply for replenishment from drug manufacturer. The manufacturer will organize product and send goods to distributor warehouse in lead time as stipulated.

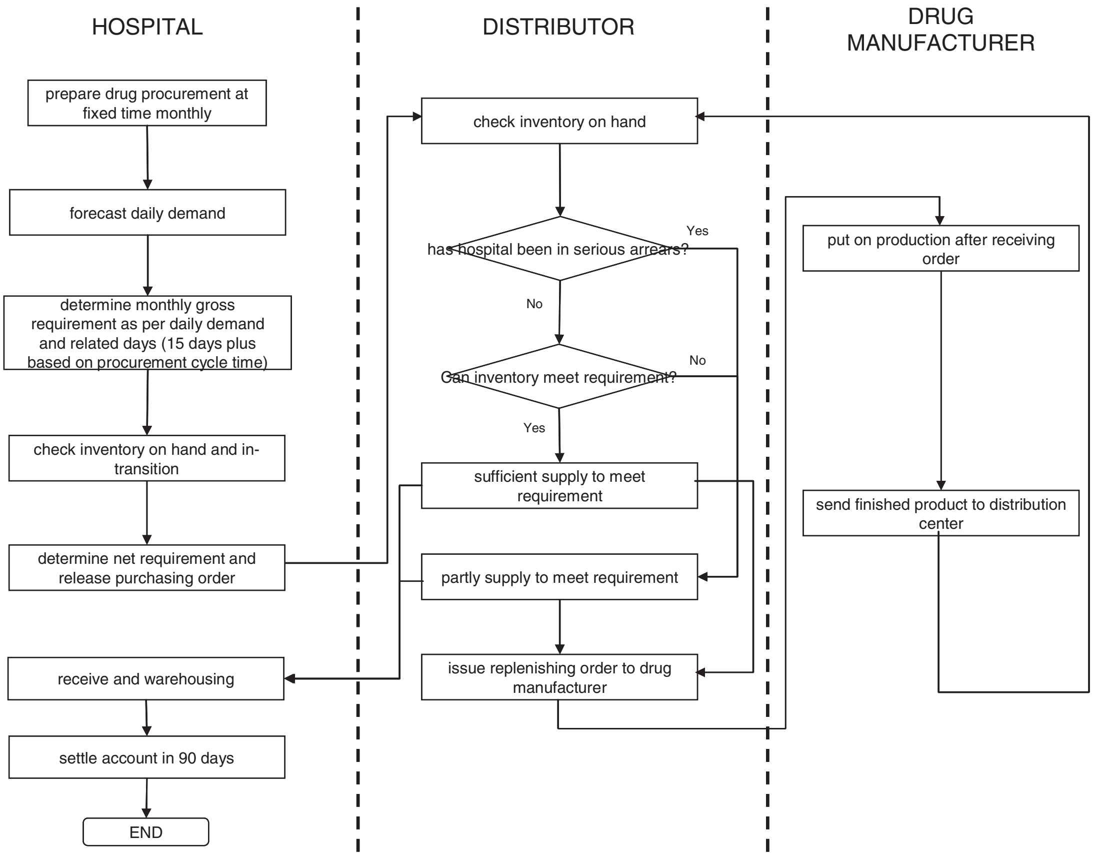

Fig. 1. Process of current drug procurement in China's public hospitals.

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Typical process or procurement in China's public hospitals is shown as Fig. 1.

Based on the flow chart, in this paper, drug "Levofloxacin Hydrochloride and Sodium Chloride Injection (左氧氟沙星氯化钠针)" is selected as research sample because this drug is most common and widely used in Chinese hospitals for restraining bacteria. Daily demands data from 3 sample hospitals of this drug are collected respectively, the key values of the demand, such as minimum value, maximum value, mean, standard deviation, are listed in Sheet 1. Unit price of the drug is ¥ 13.53 (Chinese currency, about $ 2.18).

Now, the study establishes a simulative model by System dynamic software Vensim PLE™ and input hospital data for research. Flow sketch of system dynamic is shown as Fig. 2.

3.2. Functions and parameters established

In the model, final time = 360 days, time step = 1.

Here data of hospital 1 will be base of simulation first.

(1) Factors about demand forecasting

$$daily\ demand = Integer\ (Random\ Normal\ (25, 230, 107, 93.1, 1) + 0.5)$$

Daily demand of patients is origin of whole process. In practice, daily demands are a data set in accordance with normal distribution. As per statistics data lasting 2 years from sample hospital, the mean value is 107 and standard deviation is 93.1 in first sample hospital. In this simulation model, identical mean value and standard deviation are put into the function.

Sheet 1
Key values of daily demand of sample hospital.

	Minimum	Maximum	Mean	Standard deviation
Hospital 1	25	230	107	93.1
Hospital 2	40	300	138	66.62
Hospital 3	40	370	182	85.2

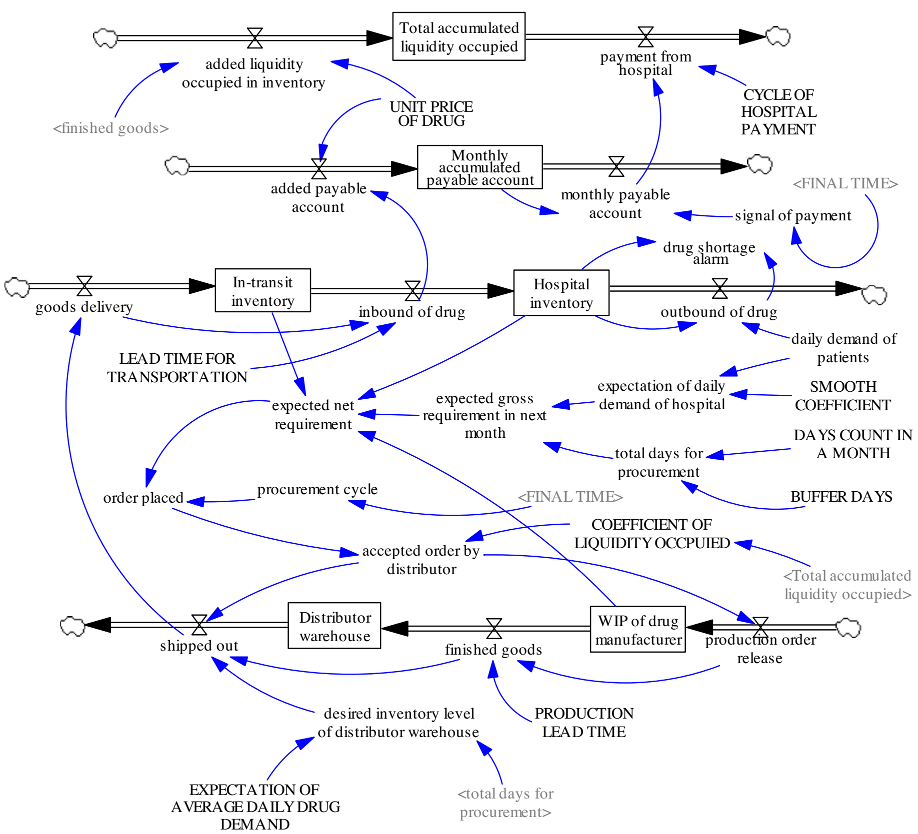

Fig. 2. Process of current drug procurement in China's public hospitals.

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$$\textit{expectation of daily demand of hospital} = \textit{Interger}(\textit{Smooth3I}\ (\textit{daily demand of patients}, \textit{smooth coefficients}, 107) + 0.5)$$

As the base of forecasting, daily demand is generated randomly, here it should be smoothed to eliminate interference of extreme values for more accurate forecasting.

Here smooth coefficients is set 30 days. Initial value is 107. Simulative effect is shown as Fig. 3.

(2) Procurement order placed

Procurement order placed includes 2 factors: how many and when to release, so net requirement and procurement cycle must be known.

$$\textit{expected net requirement} = \textit{expected gross requirement in next month - hospital inventory - in-transit inventory - WIP procurement cycle} = \textit{Pulse Train}\ (1, 1, 30, \textit{final time})$$

In this Vensim model, net requirement is calculated daily automatically, but hospital place order to the distributor just at the time point of procurement cycle, normally which could be a fixed day in a month. Here we suppose order releasing time is 1st day of every month and interval between two orders is 1 month which is fixed 30 days.

$$\textit{Order placed} = \textit{Net requirement} * \textit{procurement cycle}$$

Simulative effect is shown as Fig. 4.

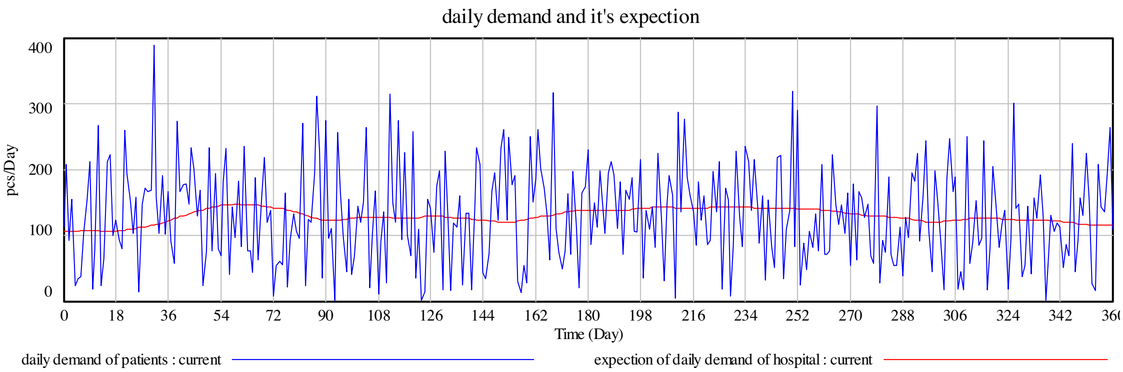

Fig. 3. Stochastic daily demand.

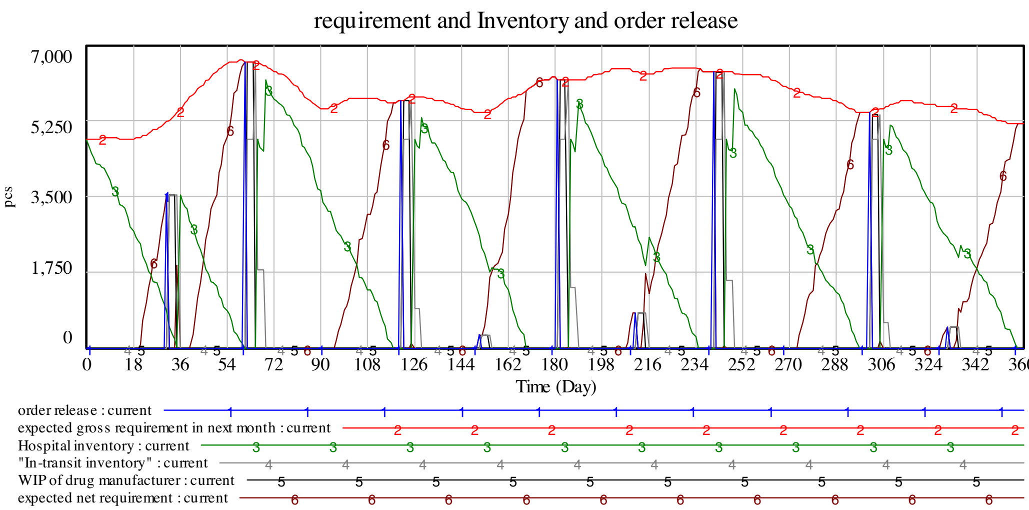

Fig. 4. Requirement and inventory in different phase.

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(3) Accepted order influenced by liquidity occupied.

Once the distributor receives order placed from hospital, he will decide whether to deliver goods as required, fully or just partly, which is based on degree of liquidity occupied by hospital. As per investigation and questionnaire survey, relationship between degree of willingness of fulfilling order and liquidity occupied is as Fig. 5.

Above relation is described in the model by table function coefficient of liquidity occupied.

$$([(0,0),(400000,1),(0,1),(300000,1),(400000,0)],(0,1),(300000,1),(335000,0.97),(360000,0.9),(375000,0.8),(390000,0.65),(395000,0.4),(400000,0)))$$

So *accepted order* = *order place* ∗ *coefficient of liquidity occupied*.

Simulative effect is shown as Fig. 6.

(4) Drug shipped out from distributor

Volume of "shipped out" can be discussed in two different situations. First situation is "accepted order by distributor" is less than inventory level of "distributor warehouse", in this case distributor will ship out goods with full demand directly. Thereafter "finished goods" is replenished to "distributor warehouse" after a "production lead time" later and kept there as supplement.

The second situation, when distributor accepts order, the volume of order is more than inventory level of distributor warehouse, first shipped out at volume on hand, the remainder due will be delivered just after finished goods arrives.

In order to simulate these two situations, function of "shipped out" is set as:

$$\textit{shipped out} = \textit{If Then Else}\ (\textit{finished goods} <= \textit{desired inventory level of distributor warehouse}, \textit{Min}(\textit{accepted order by distributor}, \textit{desired inventory level of distributor warehouse}), \textit{finished goods-desired inventory level of distributor warehouse})$$

In order to reality check, a sub flow sketch, extracted from the main sketch to check effect of function set, is shown as Fig. 7.

In sub sketch, just variables related to verification purpose are kept. Constant of "*DESIRED INVENTORY LEVEL OF DISTRIBUTOR WAREHOUSE*" is set 4500, "*PRODUCTION LEAD TIME*" is 3 days. In the model

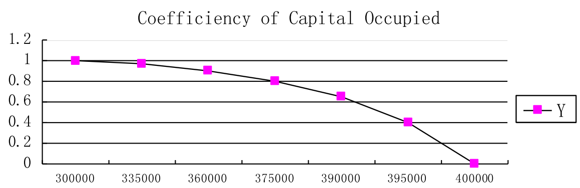

Fig. 5. Relation between order fulfill coefficient and liquidity occupied.

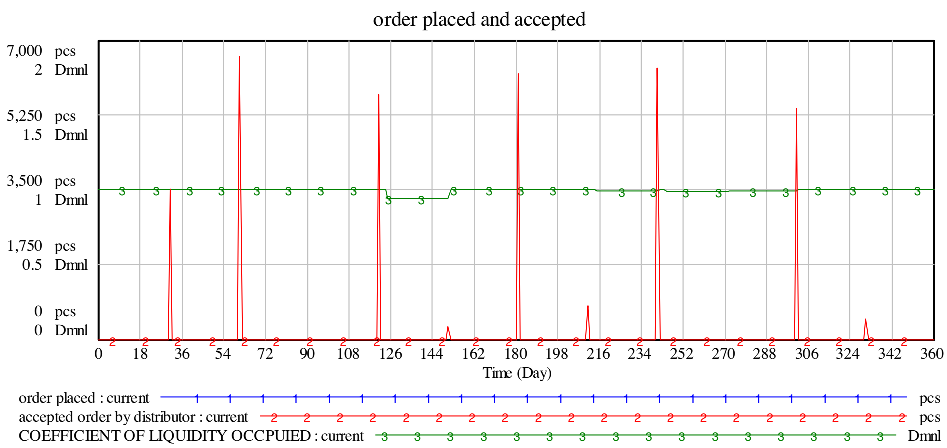

Fig. 6. Order placed and accepted.

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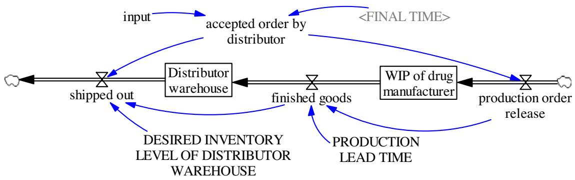

Fig. 7. Sub-sketch of flow about finished goods shipped out.

$$Initial\ time = 0,$$

$$Final\ time = 60,$$

$$Time\ step = 0.0625$$

$$Unit\ for\ time = DAY$$

Initial value of "Distributor warehouse" and "WIP of drug manufacturer" are 4500 and 0 respectively.
As demand occurs at every 30 days interval,

$$accepted\ order\ by\ distributor = Pulse\ Train(0, 1, 30, final\ time) * input$$

Now, to set "input" value simulating order accepted as 3000, 4500, 5000 respectively, "shipped out" value described in Fig. 81–3.

From above figures, we can know when accepted order is less than or equal to desired level of warehouse, the line of shipped out just appears one pulse in every procurement cycle. When accepted order is more than desired level of warehouse, the line of shipped out appears 2 pulse in every procurement cycle, with first value 4500 (level of warehouse) and second value 500 3 days later (Lead time). The result shows this model established well.

(5) Accumulated payable account

The level variable "Accumulated payable account per month" describes how many payables are accumulated in a month by a hospital. As payment cycle is 90 days as per regulation, so "Total accumulated liquidity occupied" describes total liquidity occupied of distributor for hospital.

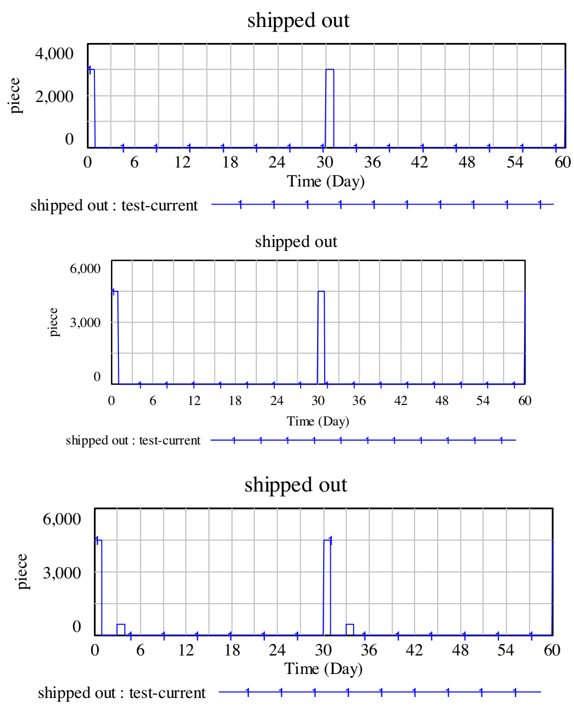

Fig. 8. (1) Shipp out line about input 3000. (2) Shipp out line about input 4500. (3) Shipp out line about input 5000.

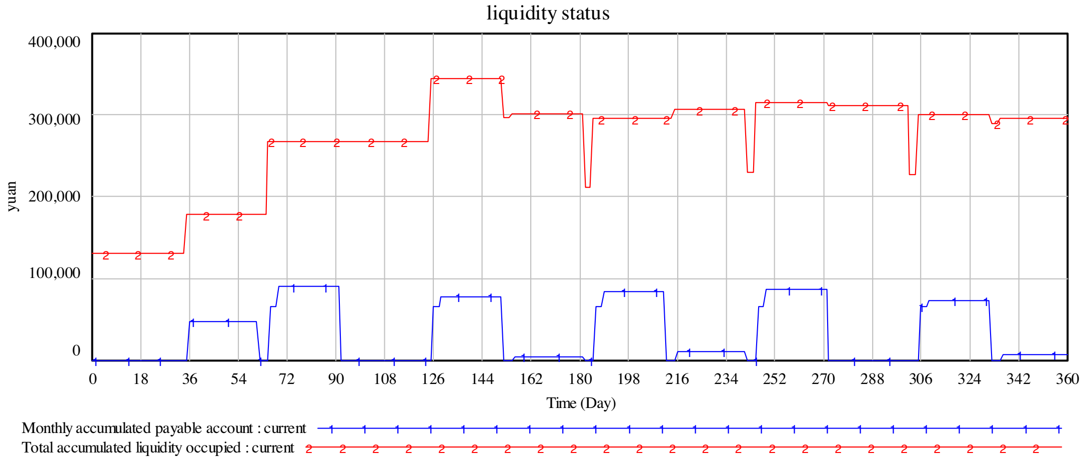

Fig. 9. Simulation about liquidity occupied.

Simulative effect is shown as Fig. 9.

About other setting of function or initial value, all will be shown on appendix.

4. Inventory Pooling System designed

4.1. Process designed of flow sketch establishment by Vensim

Inventory Pooling mode is expected to solve the problem of traditional and present procurement mode employed by public hospitals now. About advantage and disadvantage and possible risk of new mode had been discussed by Dengfeng Wu [13]. Basic flow chart of Pooling System designed is as Fig. 10.

In the new model, hospital just keep minimum level of inventory normally for 1 or 2 days demand while most of inventory kept in distribution center. Based on sharing real information of daily demand of hospital, the distribution center will deliver drug to hospital on daily frequency.

In the new model, the center will place order to drug manufacturer as periodic review method (P-system), which is not most accurate ordering method and may lead to higher inventory but it will bring joint production, transportation and buying economies and reduced administrative cost [15].

Based on the process, system dynamic model about drug Inventory Pooling is as Fig. 11.

4.2. Functions and parameters established

In the model, final time is 360. Time step is 1.

(1) Order from hospital to distribution center Order to be placed from hospital is based on following factors:
   (a) Difference between desired inventory level and current inventory level of hospital, if the latter less, motive to replenish inventory occurs.
   (b) Hospital inventory is less than patient daily demand.

So, here and below, just H1 hospital will selected out as modeling sample, functions of H2 and H3 are in same way.

Function of planned order is:

$$H1\ hospital\ planned\ order = Max\ (Max\ (H1\ hospital\ desired\ inventory\ level\text{-}H1 hospital\ inventory,\ 0),$$
$$(H1\ drug\ daily\ demand\ from\ patient\text{-}H1\ hospital\ inventory, 0))$$

Fig. 12 is simulative result about H1 hospital. From the figure volume of the planned order is normally less than that of the desired level.

Hospital desired order inventory level is variable and based on forecasted two days demand.

Forecasted daily demand is an expectation value based on daily demand accordance with normal distribution.

To take sample data of first hospital as example, function set as follows:

$$H1\ forecasted\ daily\ demand = Integer\ (SmoothI(H1\ drug\ daily\ demand\ from\ patient,\ smoothing\ coefficients,\ 107) + 0.5)$$

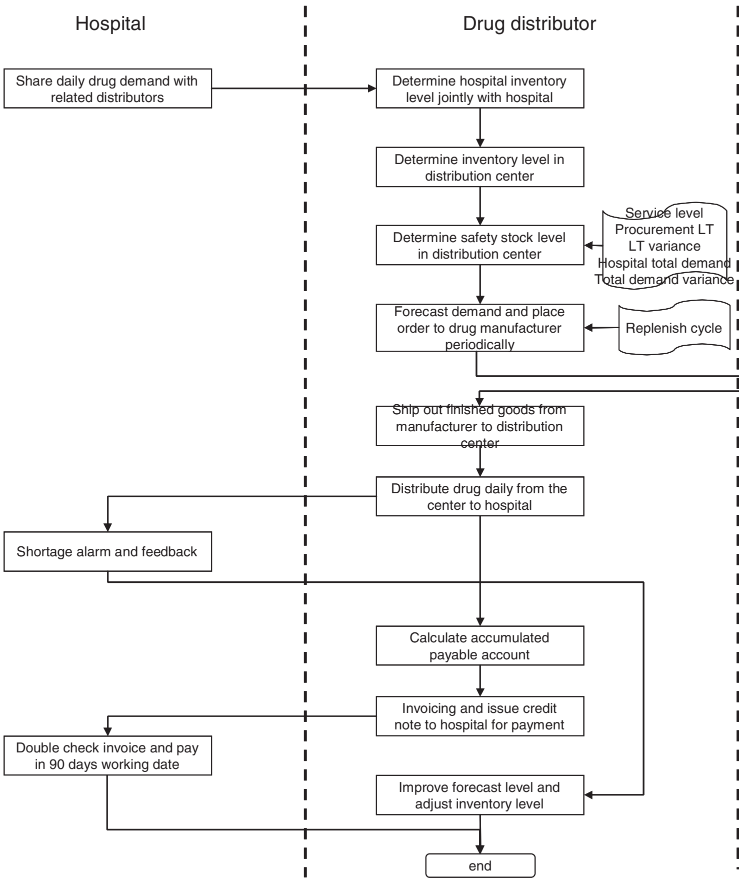

Fig. 10. Process designed of Inventory Pooling.

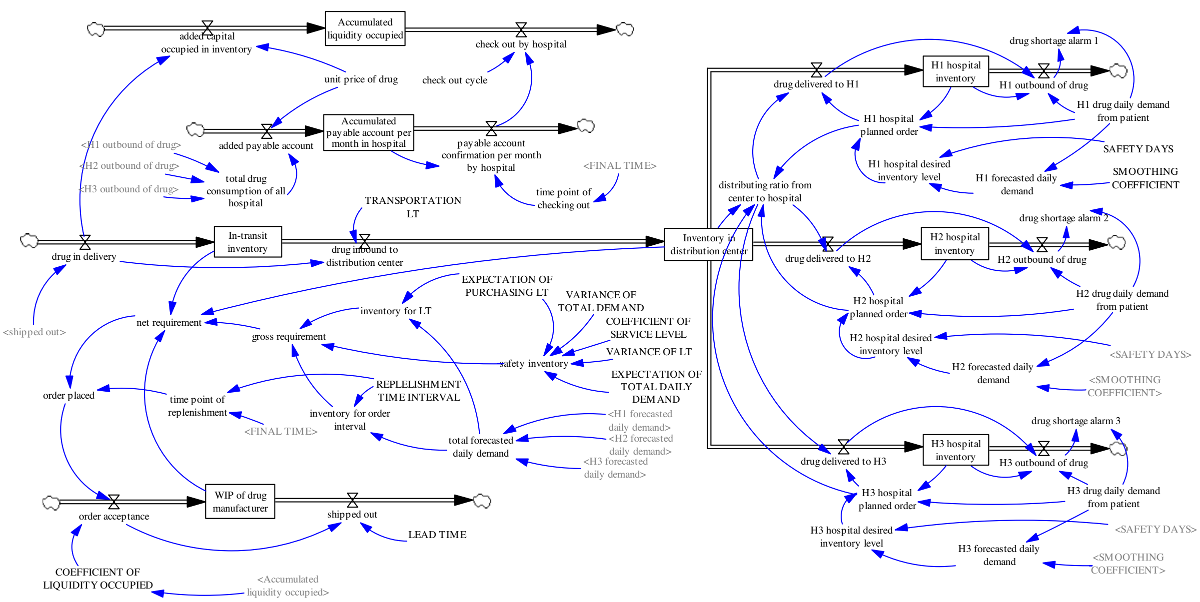

Fig. 11. Flow sketch of Inventory Pooling.

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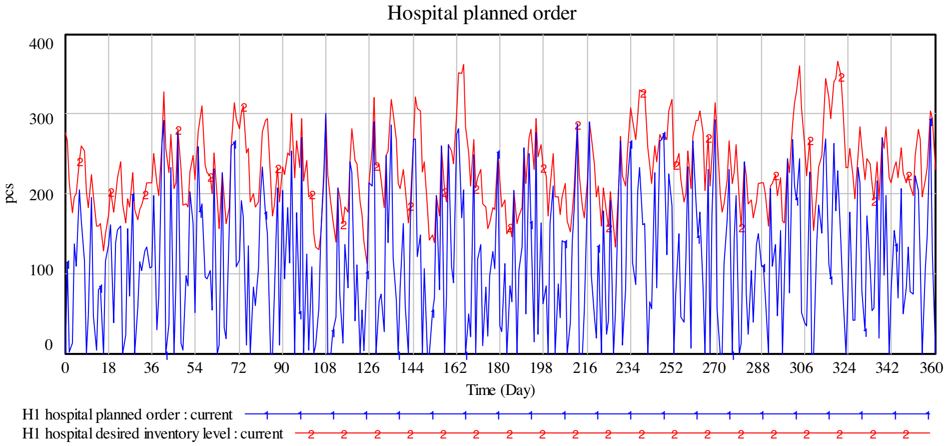

Fig. 12. Hospital planned order.

$$H1\ drug\ daily\ demand\ from\ patient = Integer\ (Random\ Normal(25, 230, 107, 93.1, 1) + 0.5)$$

25 and 230 are minimum and maximum or random variable respectively, 107 is expectation value, 93.1 is standard deviation, 107 is initial vale of demand.

Fig. 13 is simulative effect about daily demand, curve 2 is demand after smoothed as base of forecasting.

(2) Distributing ratio from center to hospital

In any case, just total demand of hospitals less than inventory in distribution center can be satisfied fully. Once more than, it means just the demand will be met partly instead of fully. As consumption, demands from different hospitals are equally important, so delivered volume will be calculated based on ratio between inventory in the center and total demand of hospitals. If total demand is less than center inventory, demand will be met 100%, otherwise, just part of demand can be satisfied.

$$\begin{aligned} Distributing\ ratio\ from\ center\ to\ hospital = {} & If\ Then\ Else\ (H1\ hospital\ planned\ order + H2\ hospital\ planned\ order \\ & + H3\ hospital\ planned\ order > Inventory\ in\ distribution\ center, \\ & Max\ (Inventory\ in\ distribution\ center,\ 0)/(H1\ hospital\ planned\ order \\ & + H2\ hospital\ planned\ order + H3\ hospital\ planned\ order), 1) \end{aligned}$$

From Fig. 14 we can learn sometimes inventory in distribution center cannot meet demands of hospitals but in that case if inventory of hospital is enough for demand, shortage will not occur and value of shortage alarms are kept on line of zero.

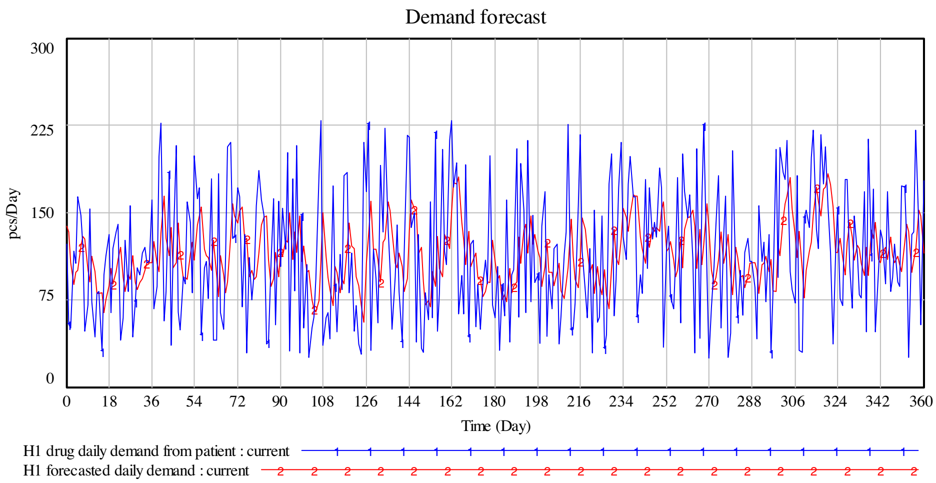

Fig. 13. Daily demand of patients.

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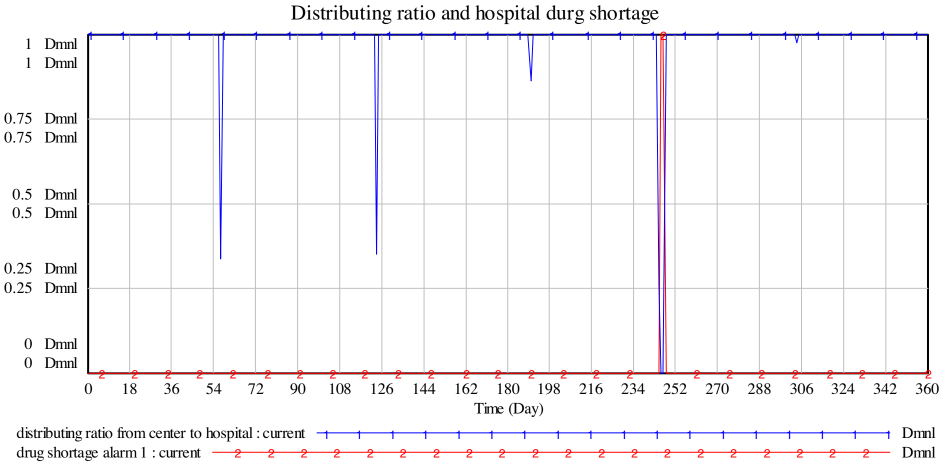

Fig. 14. Distribution ratio and shortage.

(3) Order placed

As per design of mode of Inventory Pooling, order is normally placed periodically and in fixed interval.

$$Order\ placed = net\ requirement * time\ point\ of\ replenishment$$

$$Time\ Point\ of\ Replenishment = Pulse\ train\ (0, 1,\ Replenishment\ Time\ Interval,\ Final\ Time)$$

In this paper, we focus on resolving problems of excessive liquidity occupied and drug supply shortage. About "Replenishment time interval", as per simulative result, with its value increment, amount of liquidity occupied increase as well while shortage times fluctuate. But as too frequent order will increase cost of transportation and difficulty of administration, decision should be based on balance between order frequency and liquidity occupied trend. In this paper, relationship between order frequency and liquidity occupied is shown as Sheet 2 and Fig. 15. Here interval set 7 days means order to be placed per week and just on every 7th day. It is not most accurate control as cost of holding and ordering are not available in this paper, but it can still be effective to describe a trend of performance after Pooling mode employed.

Ballou [15] demonstrated relationship between net requirement and gross requirement in P-system (periodic review method).

$$Gross\ requirement = inventory\ for\ LT + inventory\ for\ order\ interval + security\ inventory$$

About How to calculate safety inventory after employing Pooling, Dengfeng Wu [13] reasoned it in his dissertation.

$$\begin{aligned} Safety\ inventory = Integer\ (Sqrt\ (&expectation\ of\ total\ daily\ demand * expectation\ of\ total\ daily\ demand \\ &* variance\ of\ LT * variance\ of\ LT + (expectation\ of\ purchasing\ LT) * variance\ of\ total\ demand \\ &* variance\ of\ total\ demand) * coefficient\ of\ service\ level + 0.5), \end{aligned}$$

Here coefficient of service level is 2.05, which mean 98% supply assurance probability.

Simulative effect is shown as Fig. 16. From Fig. 16 we can know, net requirement is calculated daily but order is just place in fixed time cycle.

(4) Order acceptance

After order placed from distributor, drug manufacturer will decide ratio of acceptance, full acceptance or part acceptance, which depends on accumulated amount of liquidity occupied of related hospitals and supply chain.

Here, a coefficient to describe relation between acceptance ratio and accumulated amount of liquidity occupied is set by a table function shown below as per research:

Sheet 2
Interval days and shortage times and liquidity occupied.

Replenish interval (day)	1	2	3	4	5	6	7	8
Total shortage (times)	5	7	6	6	5	5	3	10
Accumulated capital occupied (¥)	630,331	633,607	636,636	639,723	643,246	645,287	649,271	651,535
Max capital occupied (¥)	835,883	844,055	847,965	855,109	854,690	862,280	873,808	879,152

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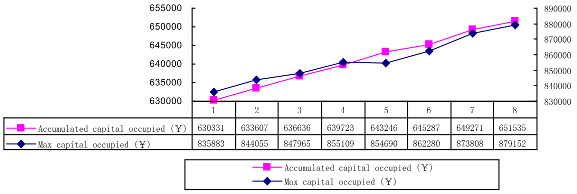

	1	2	3	4	5	6	7	8
Accumulated capital occupied (￥)	630331	633607	636636	639723	643246	645287	649271	651535
Max capital occupied (￥)	835883	844055	847965	855109	854690	862280	873808	879152

Fig. 15. Interval days and liquidity occupies relation.

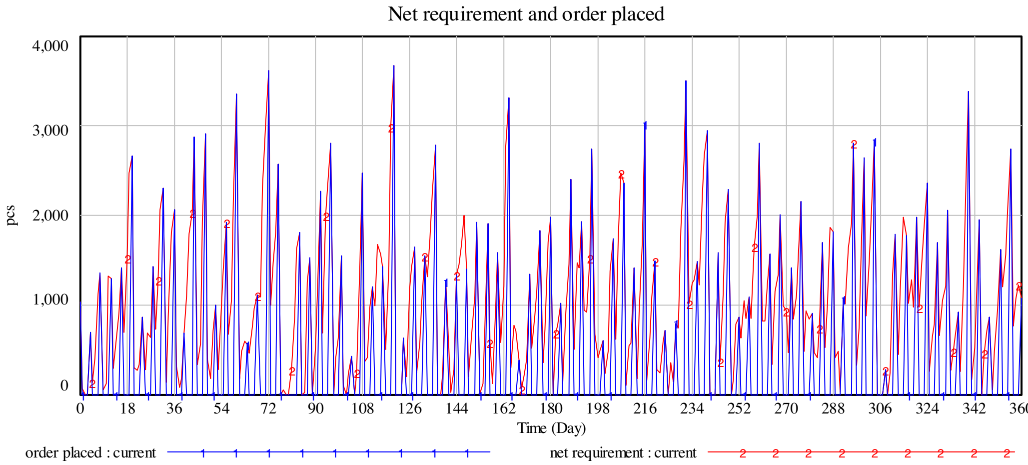

Fig. 16. Net requirement and order placed from distributor.

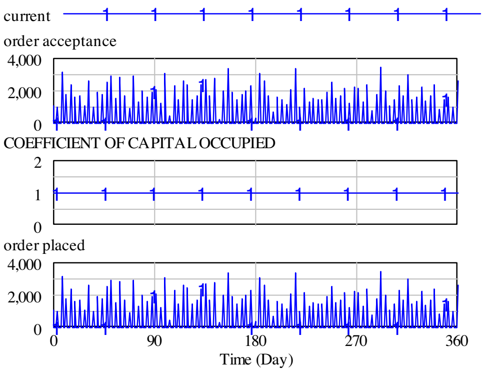

Fig. 17. Order place and accepted.

$$([(0,0)-1.1e+006,1)],(0,1),(800000,1),(900000,0.95),(1e+006,0.85),(1.05e+006,0.65),(1.11e+006,0))$$

Result after the simulation run is shown as Fig. 17.

(5) Liquidity occupied

Accumulated liquidity occupied and accumulated payable account per month in hospitals are similar to model of before improvement. Simulative effect is as Fig. 18.

5. Managerial finding

Jiujiang is a city with population about 4 million located in middle China, which is typical medium size city in China. It was also one of two pilot cities where China began its medical innovation 20 years ago.

At present, sponsored by Jiujiang University Hospital, 4 public hospitals and 1 community hospital owned by government and one supplier had joined experimental running of Pooling System.

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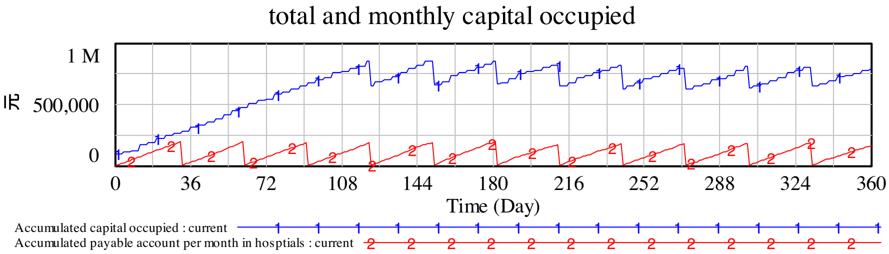

Fig. 18. Total and monthly liquidity occupied.

From data of last 8 months, the average shortage rate is about 13%, which is better than ever, but worse than expectation and simulating result in this theory research. The main cause leading to shortage is that liquidity rupture. In above research all simulations are based on assumption that hospital will settle account with supplier as statement in their purchasing contract. But actually, because of size expanding, almost all hospitals encountered problem of financial strain, which influence their ability of paying to supplier timely. Also, information system has been another problem for further Pooling System's application. In the past, all hospitals had their own IT system and could not share information about drug stock and demand with supplier periodically, timely and automatically. Now temporary solution that had been conducted is hospitals send related and necessary daily data about drug to the supplier manually instead of automatically, which is low cost but inefficient method sometimes. Once more suppliers and suppliers involved in this system, it will be inevitable that all parties must upgrade their information system in order to better data sharing. But that means huge investment needed, which will reduce enthusiasm of involvement for those parties joining Pooling System.

The cost of running Pooling System is limited in current mode. The Jiujiang University Hospital shares their warehouse as distribution center for supplier running the experiment in free charge. The involved parties have not changed their present IT system, they exchange information by email. But the solution is just effective for limited parties' involvement.

At present, we have not collected enough one-hand data to make further analysis about how all factors influence shortage in practice. It will be our next mission and goal of research. Anyway, something have been changing and developing in good trend.

6. Conclusion

In traditional procurement mode, data feature of daily demand such as value of mean and standard variation are employed in simulation mode. Performances of KPI of sample No. 2 hospitals and sample No. 3 hospital are available by simulation.

The simulative modes run 20 times based on same daily demand data distribution in math and then calculate results of shortage and liquidity occupied respectively. The average performance about KPI after 20 times running are shown in Sheet 3. The improved ratio about shortage times is 96% while that of average and maximum liquidity occupied are 27% and 30% respectively.

This paper discusses possibility of application of Inventory Pooling theory in drug supply chain. By Vensim software of system dynamic two simulation models are established for comparison of KPI data. From the comparison, Inventory Pooling will be an effective method to improve performance of drug supply and procurement in public hospitals of China. It can cut down level of liquidity occupied to avoid liquidity rupture and reduce supply shortage most likely. Here the simulations provide an evaluation method of quantitative analysis for decision and policy making.

In future research, focus will be on:

(1) How frequency of procurement cycle influence accumulate liquidity occupied and shortage times.
(2) How to achieve minimum total cost after taking factors of cost and distribution and drug supply shortage.

Sheet 3
Comparison of KPI between current mode and Inventory Pooling.

	Mean of daily demand	Standard deviation of daily demand	Times of shortages in one year	Average liquidity occupied	Maximum liquidity occupied
Hospital 1	107	93.1	42	311,612	392,867
Hospital 2	138	66.62	49	324,283	385,478
Hospital 3	182	85.2	88	354,291	454,220
Before improvement			179	990,186	1,232,565
After improvement			7	718,397	861,484
Improved ratio			96%	27%	30%

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