Optimizing Strategy of Goods Inventory Turnover in Pre-Warehouse Based on Dynamic Game Model

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Abstract: The inventory control model of fresh commodities in pre-warehouse was established by taking the fresh commodities with the shelf life of only one day as the research object. Then, starting from the uncertain demand quantity of fresh commodities, the punishment of shortage and the substitution of demand, the inventory control of pre-warehouse with the goal of maximizing the expected profit of e-commerce platform was studied. Finally, the optimal order quantity was determined and the inventory optimization strategy was summarized.

1. Introduction

The combination of e-commerce and logistics industry and its rapid development has provided a new model for the innovation of retail industry, and the major online business platforms have launched daily commodities in recent years, which mean that commodities can only be on the shelf for one day and won't be sold the next day after the sale. Fresh commodity trade, with the characteristics of small space, high flexibility, but limited inventory and throughput, mainly adopts the operation mode of immediate distribution pre-warehouse. As a result, higher requirements have been put forward for enterprise's sales plan and inventory management, and how to find the balance point between the shortage rate and the loss rate has become the focus of the fresh e-commerce platform operation research.

Previously, the characteristics of consumers' shopping behavior on fresh commodities on e-commerce platform were preliminarily investigated. It is found that consumer demand is uncertain but with a certain probability distribution, the price of fresh food fluctuates slightly and the unit price fluctuates in a small range above the minimum package price, and consumers' tolerance is low for shortages. In order to maximize revenue, the pre-warehouse e-commerce platform needs to balance the cost and profit among the gross profit of commodities, the loss caused by commodity surplus and the punishment caused by shortage of commodities. Based on these investigations and analyses, the inventory control model of fresh commodities in the pre-warehouse was established for maximizing the expected profit and providing reference value for the inventory optimization of the commercial platform.

2. Inventory Model Considering Substitution Utility of Goods

2.1 Definition of Model

The new e-commerce pre-warehouse platform needs to balance sales revenue and loss cost, so that short-term new products have a certain range of shortage rate, so as to achieve maximum benefits. It can be seen that the shortage rate is an important index in the current retail inventory management [1]. The reasons are as follows: on the one hand, consumers have diversified selectivity with the diversification of consumers' shopping channels and the substitution of target commodities, so that the shortage of commodities directly affects the sales of commodities. On the other hand, consumers prefer to shop in stores with abundant and diversified supply according to

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the research, while the shortage leads consumers to flow to other platforms, thus causing the reduction of passenger flow [2].

The substitution effect of commodity demand should be taken into account according to the actual situation of current commodity sales. Consumers of e-commerce platform purchase their substitute commodities in the store, or abandon shopping and turn to other e-commerce platforms or channels when the commodities needed are out of inventory. The former situation doesn't lead to loss of sales, while the latter not only affects the sale of the commodities, but also causes the penalty of shortage. The specific sales process is shown in Fig. 1.

To sum up, demand substitution effect was added on the basis of the newsboy model of buyback contract and shortage penalty, and the inventory control model of fresh commodities in pre-warehouse was established for maximizing the direct and indirect expected profits of commodities. Then the quantity of inventory and expected profits were calculated and the influence of demand substitution effect on inventory quantity and expected profit was analyzed through comparison [3].

2.2 Parameters and Assumptions

Model Parameter

The parameters of the model are described as follows:

P means retail price of unit commodity on the platform of electronic commerce (RMB);

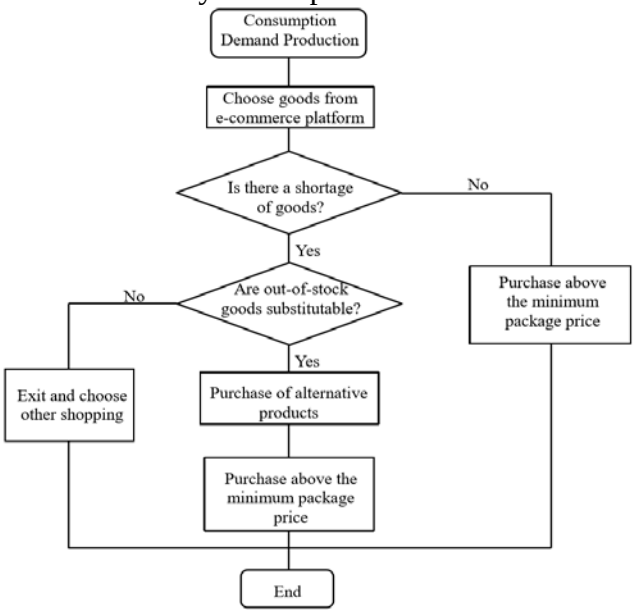

Fig.1 Consumer Shopping Behavior Flow of Pre-Warehouse e-Commerce Platform

V refers to the average purchase cost per unit commodity (yuan) such as the purchase cost, processing cost and transportation cost of commodities;

G represents surplus value of unit commodity (yuan);

Q represents the quantity of commodities ordered (individual), among which, the whole box of commodities ordered is out of considered and the minimum order quantity is a single;

X represents the quantity of demand for commodities (individual), which obeys the random distribution of probability density function $f(x)$, and it is assumed that the demand for commodities obeys uniform distribution within a certain range;

S represents the penalty for commodities shortage (RMB), which is related to the average unit price of passengers and gross interest rate;

A represents the fixed cost of commodities ordered daily;

r represents the substitutable ratio of commodities within (0,1) related to the characteristics of commodities;

w refers to gross profit from sales of substitutes, demand sales are converted into sales of other commodities in the e-commerce platform when commodities are out of inventory, thus resulting in

average gross profit income;

H refers to the average quantity of commodity demand, expressed by $\int_0^{+\infty} xf(x)dx$;

represents average shortage, expressed by $\int_Q^{+\infty}(x-Q)f(x)dx$;

$\prod$ represents the net profit of the commodity without considering the substitution utility of the commodity;

$\prod_T$ represents the net profit generated by the commodity when the substitution utility is considered, including the profit generated by the direct sale and the profit generated by the substitution sale when the commodities are out of inventory;

Q^* refers to the optimal quantity of inventory without considering the substitution utility of commodities;

Q_T^* represents the optimal quantity of inventory with the consideration of the substitution utility of commodities.

Model Hypothesis

Consumption behavior characteristics are different when consumers shop online and offline channels. The price of commodities is not limited when consuming through offline channels. However, there will inevitably be time cost because of the behavior of entering stores, so consumers will choose to buy substitute commodity or turn to other channels for consumption when the commodities are out of inventory. Consumers mostly choose only one e-commerce platform for shopping because of the existence of distribution costs. In $E[S(Q)]$addition, consumers can choose substitute commodity for consumption on this e-commerce platform or choose other channels for consumption when a commodity is out of inventory [4]. Specific assumptions are as follows:

① The uncertainty in demand for commodity is assumed to be X, which is a random variable subject to probability density function $f(x)$, and the cumulative distribution function is assumed to be $F(x)$.②Regardless of the influence of order quantity on the procurement cost, the unit procurement cost of commodities is assumed to be V.③ The fixed unit price without the consideration of discount promotion is assumed to be P.④ The supply capacity of the central warehouse can meet the order quantity of the pre-warehouse.⑤ There is only one order opportunity per sales day to meet the needs of customers on that day. ⑥ The unit residual value of the surplus commodity is assumed to be G at the end of a single sales day.⑦ If the commodities are sold out before the end of the sales day, it is defined as the situation of shortage, and the consumption demand with r proportion is transformed in the same shop in the quantity of shortage, while the gross profit obtained by the transformed sales is w, and the proportion of the other part $(1-r)$ is the loss of sales, which forms the penalty of shortage.

2.3 Establishment of Model

The profit of e-commerce platform depends on the sales situation of commodities, gross profit structure, loss cost, shortage penalty and other factors, so that the model is described as follows:

(1)The demand for commodities *X* obeys the random distribution of probability density function $f(x)$. So when the order quantity is *Q*, the sales volume of commodities is:

$$\min(X,Q) \tag{1}$$

(2)The surplus of commodity sales is generated when the order quantity is larger than the demand quantity, and the unit surplus value of commodity is *G*, which is less than the unit purchase cost, thus, the profit from the sale of this commodity is as follows:

$$\prod_T(Q)=(P-V)*X-(V-G)*(Q-X)-A \tag{2}$$

(3)With the order quantity less than the demand quantity, there are two kinds of consumer

behavior when the commodities are out of inventory. Assuming that the conversion probability of the same e-commerce platform is the commodity substitution rate, which is equal to $r(0<r<1)$, the gross profit for the sale of substitutes is w, and the probability of the penalty for shortage is (1-*r*), thus, the profit of e-commerce platform is:

$$\prod_T(Q)=[(P-V)*X+rw*(X-Q)-(1-r)*S(X-Q)]f(x)dx-A \tag{3}$$

In summary, the expected benefits of the commodity both direct and indirect are as follows:

$$\begin{aligned} E[\prod_T(Q)] &= \int_0^Q [PX+G(Q-X)-VQ]f(x)dx \\ &+\int_Q^{+\infty}[(P-V)*Q+rw(X-Q)-(1-R)*S(S-Q)]f(x)dx-A \end{aligned} \tag{4}$$

Assuming that the operators of e-commerce platform are risk-neutral, the order is to maximize revenue. Similarly, it can be proved that the above formula is a strict concave function. For *Q*, the first derivative is obtained, and $\frac{dE[\prod_T(Q)]}{d(Q)}=0$.

The formula can be obtained by calculation:

$$F(Q_T^*)=\frac{P-V-rw+(1-r)S}{P-rw+(1-r)S-G} \tag{5}$$

The optimal order quantity is obtained Q_T^*:

$$Q_T^*=F^{-1}\left[\frac{P-V-rw+(1-r)S}{P-rw+(1-r)S-G}\right] \tag{6}$$

Thus, the maximum expected return of the pre-warehouse can be obtained:

$$E[\prod_T(Q_T^*)]=(P-G)\mu-[(P-G+S)-r(w+S)]\int_{Q_T^*}^{+\infty}Xf(x)dx-A \tag{7}$$

2.4 Result Analysis

From the analysis above, it can be seen that the substitution effect of commodities exists in the consumer's consumption behavior whether or not the substitution effect of commodities is taken into account in the decision-making of inventory in real life, thus, the calculation is carried out in Formula (7) when calculating profits.

Conclusion 1: the quantity of commodities in inventory is affected by the ratio of gross profit to order loss and the penalty for commodities shortage when the penalty for commodities shortage is not zero and the replacement rate is zero.

When *r = 0*, $Q^*=Q_{T^*}=F^{-1}\left(\frac{P-V+S}{P-g+S}\right)$, the profit is equal.

$$E[\prod_T(Q^*)]=E[\prod_T(Q_T{}^*)]=(p-g)\mu-[(p-g+S)\int_{Q^*}^{+\infty}Xf(x)dx-A \tag{8}$$

Conclusion 2: the decision-making model considering the substitutability of commodity demand can reduce the quantity of commodities in inventory when the penalty for commodities shortage is not zero and the demand substitutability is greater than 0, namely, $Q^*>Q_{T^*}$.

To prove:

$$Q^*-Q_T^*=F^{-1}\left[\frac{P-V-rw+(1-r)S}{P-rw+(1-r)S-G}\right]-F^{-1}\left(\frac{P-V+S}{P-g+S}\right) \tag{9}$$

Among them, $F(x)$ is the expression of distribution function, so it is monotonous.

$$\frac{P-V-rw+(1-r)S}{P-rw+(1-r)S-g}=\frac{P-V+S-rw-rS}{P-g+S-rw-rS}>\frac{P-V+S}{P-g+S}$$

Therefore, $Q^*-Q_{T^*}>0$, and it is proved.

Conclusion 3: the expected profit of the decision-making model considering commodity substitutability is high when the penalty for commodities shortage is not zero and the demand substitutability is greater than 0, that is, $E[\prod_T(Q_T{}^*)]<E[\prod_T(Q^*)]$.

To prove:

$$\begin{aligned}&E[\prod_T(Q_T{}^*)]-E[\prod_T(Q^*)]\\&=\left\{(P-G)\mu-[(P-G+S)-r(w+S)]\int_{Q^*}^{\infty}xf(x)dx\right\}\\&-\left\{(P-G)\mu-(P-G+S)\int_{Q^*}^{\infty}xf(x)dx\right\}\\&=(P-G+S)*\left[\int_{Q}^{+\infty}xf(x)dx-\int_{Q_{T^*}}^{+\infty}xf(x)dx\right]+r(w+S)*\int_{Q_{T^*}}^{+\infty}xf(x)dx\end{aligned}\tag{10}$$

Among them, $Q^*>Q_{T^*}$, therefore, $\int_{Q}^{+\infty}xf(x)dx-\int_{Q_{T^*}}^{+\infty}xf(x)dx>0$, the values of r, w and S are all greater than 0, so $E[\prod_T(Q_T{}^*)]-E[\prod_T(Q^*)]>0$, and thus it is proved.

3. Numerical Simulation Analysis

3.1 Analysis of Influence Parameters

Ratio of Gross Profit to Residual Loss in Commodity Sales

Ratio of gross profit to residual loss of a commodity represents the ratio of gross profit of a commodity sold to the loss of the remaining commodity [5]. The value of $Q^*=F^{-1}\left(\frac{P-V}{P-G}\right)$ is equal to the ratio of area of A1 to area of A2 when the values of S, w and r are equal to 0, as shown in Fig. 2. The surplus value of the commodity is the key factor to determine the ratio when the price and gross profit of a commodity remain unchanged, while the unit surplus value of the commodity is negatively correlated with the loss of the sale surplus. Therefore, it is urgent for the supplier to optimize the inventory strategy and reduce the loss cost.

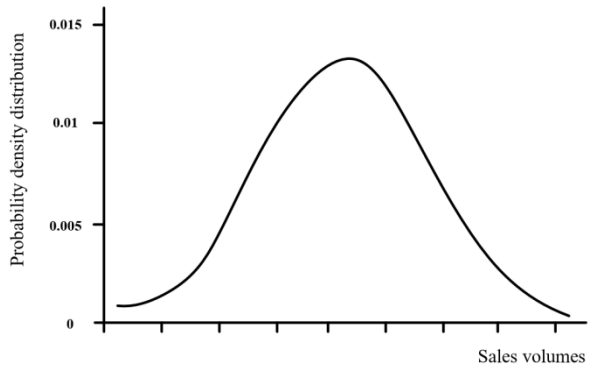

Fig.2 The Dependent Factor of the Value of Q^*

Penalty for Unit Shortage of Commodities

Shortage penalty refers to the loss of sales when commodities are out of inventory, which mainly depends on the extent to which the shortage of commodities affects the loss of sales profits. Existing research shows that there are two main cases of shortage penalty: one is that the sales volume of related commodities is lost while the customers are not, and the demand for related commodities decreases when the commodities are out of inventory. The other is the order loss,

consumers who have strong demand for commodities turn to other shopping channels to meet their needs when commodities are out of inventory.

Demand Substitutability of Commodities

Demand substitution of commodities refers to the probability that consumers choose to buy other commodities when commodities are out of inventory, the higher the substitution rate of commodities is, the smaller the probability of loss of sales can be, and the value of which is influenced by the characteristics of commodities. Fresh food mostly belongs to functional food with generally large substitution degree.

Gross Profit on The Sale of Alternatives

Part of the demand can be translated into sales of other commodities when a commodity is out of inventory, and other commodities are called demand substitutes, and their gross profit can be calculated. The value affects the decision-making of e-commerce platform.

3.2 Parameter Sensitivity Analysis

A commodity of the pre-warehouse e-commerce platform was selected as the research object, the unit purchase price V of the commodity was set, and the sensitivity of *(P-V), (V-G), S, w* and r to the quantity of commodities in inventory and profit was obtained; then the comparison between the quantity of reserve and the expected profit under the two decision-making models was verified by taking a fruit commodity with a constant sales level as an example, and the following assumptions were made for basic commodities after many calculations (as shown in Table I):

Table 1 Parameters of The Goods Selected for Example

Parameter	P	V	G	r	S	w	$f(x)$
Initial value	20	10	5	0.5	8	6	U(60,100)

Formulas (6) and (2) were used to obtain two inventory control decision models. The results are shown in Table II.

Table 2 Calculation Results Of the Quantity of Inventory and Expected Profit Selected

Replaceable inventory decision without considering commodity demand		Replaceable inventory decision considering commodity demand	
Q^*	$E[\prod_s(Q^*)]$	Q_T^*	$E[\prod_s(Q_T^2)]$
92	727.2	88	731.2

The calculation results in Table II verified that the quantity of inventory decreases and the expected profit increases when the demand of commodities can be substituted in the pre-warehouse e-commerce platform.

The influence of the above parameters on the relationship between the quantity of commodities in inventory and the expected profit was calculated. And on the premise of a certain commodity selling price, purchasing price and probability density function of demand subject, the influence and sensitivity of unit residual value, unit shortage penalty and demand substitution rate on reserve and expected profit were calculated respectively. However, the average gross margin of substitute sales was difficult to measure, because it was impossible to measure which specific commodity the sale converted into when the commodity was out of inventory, and it could only be synthetically estimated based on the dynamic change of sales data of e-commerce platform and consumer behavior habits. Therefore, the average gross margin of substitute sales was set here to carry on the analysis.

(1)The sensitivity of the change of gross profit of sales to the quantity of inventory and expected profit was calculated, and the effect of every 2 yuan increase in commodity sales price on the calculation results was calculated when $P=[10,30]$ on the basis of keeping the other parameters unchanged.

As can be seen from Fig. 3, the number of commodities in inventory keeps increasing and the expected profit is increasing when gross profit of commodities sales increases; the order quantity is 67 but not 0 and the expected profit from direct sales is 0 when gross profit of commodities sales in special cases is 0, and it can be seen that commodity shortage results in shortage penalty.

Considering the overall sales, e-commerce platform still needs to inventory up to meet the diverse needs of consumers.

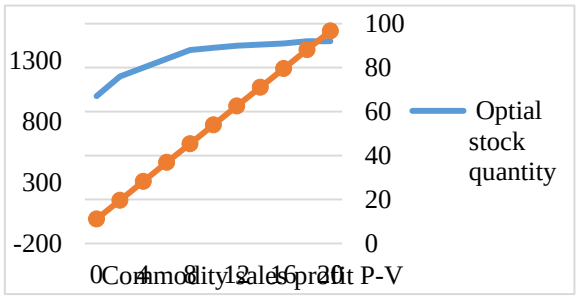

Fig.3 The Effect of Gross Profit Changes on the Quantity and Profit of Goods in Inventory

(2)The sensitivity of unit loss $V-G$ of surplus commodities to the quantity of inventory and expected profit was calculated, and the effect of every 1 yuan decrease in surplus value on the calculation results was calculated when $G=[0,10]$ on the basis of keeping other parameters unchanged.

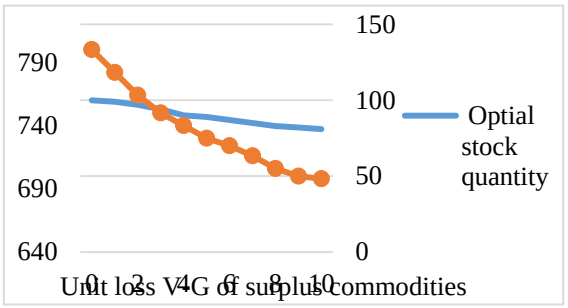

Fig.4 The Impact of Unit Loss of Surplus Commodities on the Quantity of Inventory and Profit

As can be seen from Fig. 4, the surplus value of commodities, the optimal quantity of inventory and the maximum expected profit gradually decreases when the unit loss of surplus commodities increases. And the sensitivity to the quantity of inventory and expected profit is small when the unit value of surplus commodities is large.

(3)The sensitivity of change in demand substitutability r to the quantity of inventory and expected profit was calculated, and the influence of every 0.1 increase in the substitution probability of commodity demand on the calculation results was calculated when $r=[0,1]$ on the basis of keeping other parameters unchanged.

As can be seen from Fig. 5, the greater the substitutability of commodities, the greater the sensitivity of the impact on the quantity of inventory and expected profits can be.

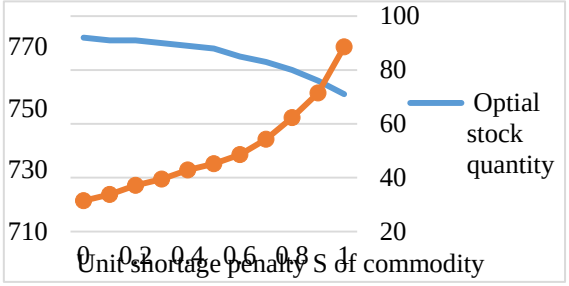

Fig.5 Impact of Changes in Substitutability r of Commodities on the Quantity of Inventory and Expected Profit

(4)The sensitivity of unit shortage penalty S to the quantity of inventory and expected profit was calculated, and the effect of every 2 yuan increase in unit shortage penalty on the calculation results was calculated when $S=[0,20]$ on the basis of keeping other parameters unchanged.

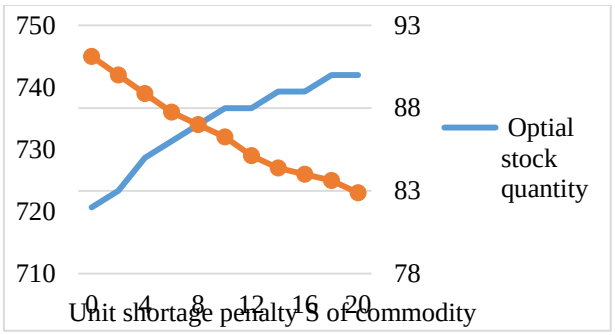

Fig.6 The Impact of Unit Shortage Penalty s on the Quantity of Inventory and Expected Profit

As can be seen from Fig. 6, the optimal quantity of commodities in inventory keeps increasing, while the maximum expected profit decreases gradually when the unit shortage penalty of commodities increases. At the same time, the sensitivity of the impact on the optimal inventory size and the maximum expected profit is low when the penalty of shortage is large.

3.3 Example Analysis

The gross profit, residual loss, demand substitution rate and shortage penalty of commodities were analyzed numerically above, and the impact of the changes of the above parameters on the quantity of commodities in inventory and profits was comprehensively analyzed in this section. There were two kinds of commodities: high gross profit commodities and low gross profit commodities, the residual loss of sales was divided into three categories: high, medium and low, and the substitutability of commodities was divided into three categories: low, medium and high. At the same time, the penalty of shortage was divided into two categories: low and high, and the fixed purchasing cost of commodities was set; thus, the quantity of commodities in inventory and the expected profits obtained under different conditions were listed separately.

P : 12 and 25, the values of $P-V$ were 2 and 15;

G : 8, 5 and 2, the values of $V-G$ were 2, 5 and 8;

r : 0.2, 0.5 and 0.8;

S : 2 and 10;

Inventory decision model was used to simulate the commodities when the values of each parameter were different. The quantity of inventory and the expected profit are shown in Table III and Table IV, respectively.

The simulation results in Table III and Table IV show that under the assumption that the demand distribution of different commodities was the same, the following conclusions could be drawn:

(1) Optimal quantity of commodities was the largest with the high gross profit of commodities, low residual loss, strong demand substitutability and high penalty of shortage; but the direct profit of sales was the largest when the penalty of shortage was low.

This is in line with the sales law in practice, especially for those with high gross profit but low loss goods, which can achieve the highest sales profits. However, in the actual business rules, there is usually no such ideal. Commodities with higher gross profit are usually sold at higher prices, so the sales volume is lower. Therefore, these commodities are usually C commodities of e-commerce platforms, mainly used to improve the average gross profit of e-commerce platforms.

(2) Optimal inventory quantity of commodities was lower than the minimum sales quantity of commodities with low gross profit of commodities, moderate or high residual loss, and strong demand substitutability.

Through realistic analysis, it is found that this situation exists in reality. Commodities with low gross profit and high substitution are usually promotional commodities of e-commerce platforms, that is to say, each promotional commodity has sales substitutes. Similar to the “limited purchase” commodities of e-commerce platforms, the main function is to drain. Although the direct gross profit of sales is low, it helps to increase passenger flow and cultivate consumer habits, and produces a higher profit of profile.

(3) Ratio of gross profit to residual loss was the most important factor affecting the quantity of commodities in inventory and expected profit. From the research results of behavioral inventory management, it conforms to the retail law of retailers. The higher the gross profit, the lower the loss, the more the retailer's inventory will be than the average sales volume, almost close to the maximum sales volume. The reason is that the expected gross profit income can balance the loss cost caused by the residual loss.

Table 3 Optimal Inventory Quantity of Inventory Decision Model with Different Parameters

$P-V$	$V-G$	r	$S=2$	$S=10$
15	8	0.2	86	89
		0.5	84	87
		0.8	81	83
	5	0.2	90	92
		0.5	88	90
		0.8	86	87
	2	0.2	95	94
		0.5	94	96
		0.8	93	97
2	8	0.2	71	82
		0.5	60	73
		0.8	36	52
	5	0.2	75	86
		0.5	60	78
		0.8	0	44
	2	0.8	84	60
		0.5	60	87
		0.2	60	93

Table 4 Expected Profit Of Inventory Decision Model with Different Parameters

$P-V$	$V-G$	r	$S=2$	$S=10$
15	8	0.2	1096	1084
		0.5	1104	1093
		0.8	1115	1109
	5	0.2	1125	1119
		0.5	1129	1124
		0.8	1136	1132
	2	0.2	1165	1166
		0.5	1166	1164
		0.8	1167	1163
2	8	0.2	196.4	153.5
		0.5	240	186.7
		0.8	336	273.9
	5	0.2	202.5	174.7
		0.5	240	195.6
		0.8	390	278.9
	2	0.8	216	268
		0.5	240	213.3
		0.2	300	207

(4) Penalty of shortage had the greatest impact on the quantity of commodities in inventory when gross profit of commodities was low and residual loss was low. The higher the penalty of shortage, the higher the quantity of commodities could be in inventory.

From the analysis of practical significance, it conforms to the sales law of commodities with higher level of related sales or more functional sales, such as the goods in special situations or the seasonal goods. Therefore, for the inventory control model of this kind of commodity, the operation and management of the fresh e-commerce in pre-warehouse should consider not only the sales quantity and gross profit loss of the commodity, but also the value of the penalty for goods out of inventory. For example, through the analysis of sales data, when the goods are out of inventory, the

changing trend of related goods and orders should be observed in time, so as to obtain the maximum expected profit of e-commerce platform.

(5) Demand substitution had the greatest impact on the quantity of commodities in inventory when gross profit was low and surplus loss was high or moderate.

From the practical significance analysis, it mainly conforms to the regular vegetable commodity management law. Affected by the particularity of the commodity itself, the wider the width of the same category of commodities, the lower the quantity of reserve can be; the lower the width of the same category of commodities, the larger the quantity of reserve can be. Therefore, for the inventory control model of commodities with large breadth, the operation and management of pre-warehouse e-commerce platform should focus on measuring the demand substitution rate of commodities. Through the analysis of historical sales data, when a commodity is out of inventory, the sales trend of other substitute commodities should be observed in time, so as to reduce the number of goods in the pre-warehouse and improve the utilization of warehouse space.

4. Conclusions

With the continuous improvement of consumer demands and the change of retail mode, the demand for turnover of inventory commodities is becoming higher and higher in the retail industry. Based on this, the optimization strategy of goods inventory turnover in pre-warehouse based on dynamic game model was studied in this paper. First of all, the inventory model of commodities in pre-warehouse was established, and the inventory optimization problem of commodities with short shelf life of only one day was studied. Then, by solving the game model, the expected profit of e-commerce platform was maximized, and the optimal order quantity of goods was calculated. Finally, the following conclusions were drawn: The optimal quantity of commodities was the largest with high gross profit of commodities, low loss of surplus, strong demand substitutability and high penalty of shortage, while the direct profit was the largest when the penalty of shortage was low. The optimal inventory quantity of commodities was lower than the minimum sales quantity of commodities with low gross profit of commodities, moderate or high residual loss, and strong demand substitutability. The ratio of gross profit to residual loss was the most important factor affecting the quantity of commodities in inventory and expected profit. The penalty of shortage had the greatest impact on the quantity of commodities in inventory when gross profit of commodities and residual loss were low. The higher the penalty of shortage was, the higher the quantity of commodities could be in inventory. The demand substitution had the greatest impact on the quantity of commodities in inventory with low gross profit and high or moderate surplus loss. This study can provide a theoretical reference for the wide application of inventory turnover and game model in retail industry, but the model still needs verification by further examples, and the parameters need to be adjusted according to the examples to improve the applicability of the model.

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