DETERIORATING PRODUCTS SHIPMENTS PLANNING IMPROVING

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Abstract The wastage minimization problem of products with limited expiration date keeping required service level is studied. Short literature review is presented. Major approaches for deteriorating stock planning are listed. Some related researches are provided. The problem is stated considering industry specifics of non from concentrate juice production. The drawbacks of initial planning approach are shown. Some market conditions and business processes influencing supply chain performance are presented. The algorithm for wastage volume estimation is developed. It is shown that the shipments planning process paying attention to product limited shelf life may reduce the costs significantly, despite that in certain situations it may be better to consider product delisting. The safety stock level affects the system's performance indicators greatly, but is hard to calculate analytically. The vba-excel-based tool for the products shipment planning is developed, analyzed and implemented. The simulation model reflecting the planning tool logic is developed. Several simulation experiments are performed.

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1. INTRODUCTION

The problem of inventory management considering product deterioration is being studied for a few decades already, and is still actual for the analysis nowadays. There are several industries where this problem can be especially critical: FMCG (especially in food industry), some types of manufacturing, medical industry and typography. For example, according to the research by Buzby et al (Buzby, Wells, Axtman, & Mickey, 2009) the rate of wastage of certain products in US food retail networks may exceed 10%.

Introducing the only additional variable of the product best before date and, thus, the product deterioration, in some cases complicate the planning process radically. Besides, the inventory management algorithm is usually modified: if the risk of wastage (write-offs) is increasing, some additional processes of demand stimulation are deployed. The more expensive the product is, the greater the impact of write-offs on the overall costs is.

The most resource consuming planning process is applied to the products with relatively long best before period. The single period model (“newsvendor problem”) cannot be applied because there should be at least several planning periods. But the period of deterioration is not so long that only a slight correction of economic order quantity could be enough. The approach to planning of this “intermediate” product type strongly depends on industry specifics. It often requires complex measures including coordination of company’s departments or supply chain elements.

First formulations of the deteriorating products inventory management problem were made in late 50’s of XX century in the works of Derman and Klein (Derman & Klein, 1958), and Arrow et al (Arrow, Karlin & Scarf, 1958).

There are a lot of variations of the problem formulation after more than fifty years of study. For instance, these parameters are considered in different combinations: demand distribution, existence of discounts, acceptance of shortages and replenishment of the shortages possibility in future periods, amount of products, amount of warehouses, number of supply chain tiers, payment postponement acceptance.

One the earliest review article concerning deteriorating products inventory management problems is the research of Nahmias (Nahmias, 1980). It is aimed at the analysis of mathematical methods applied for the problem. The classification of problem statements is presented. The author highlights the problem’s computational complexity rapid growth when the number of planning periods to consider increases. Some analytic solutions are based on Markov Chains or queue theory and are very complex to calculate. It should be mentioned that simulation is used in some researches, despite early publication date (1980). Applying the models to practice is studied too, for example, the supply of hospitals with donor blood. The short analysis of the problem statement is given in Nahmais (Nahmias, 2011). The Wilson’s EOQ formulae is used as a starting point for future mathematical transformations in the majority of the researches (Дыбская, Зайцев, Сергеев, Стерлигова, Логистика, 2008).

A lot of models were developed and adapted for planning of inventory which deteriorating process is not typical and cannot be described with basic mathematical formulation. For example, in Tekin et al (Tekin, Gurler, & Berk, 2001) the model for deteriorating stock of composite materials used in aerospace industry is studied. The distinguishing feature of this raw material is that it starts deteriorating immediately after it is moved from raw materials warehouse (special environmental conditions are kept there) to production line.

Deep analysis of blood inventory management (the donor blood is one of representing examples of deteriorating products – it has a 21 days product life) is given at Stanger et al (Stanger, Yates, Wilding, & Cotton, 2011). Many of author's recommendations can be applied to other industries' supply chains. The research is valuable due to detailed literature and methods review. Furthermore, it contains administrative recommendations concerning the inventory management organization for this very specific product.

Fundamental difference of inventory models for deteriorating stock from the classical inventory models is that not only the amount of stock is taken in consideration, but the distribution of remaining shelf life among the product batches too.

The dimension of the variable describing the stock is proportional to overall shelf life of the product expressed in number of periods. As a result, the calculation of optimal inventory policy is justified for the products with relatively short product life. The variable vector makes future states of the system be dependent on previous states. This fact complicates the calculations drastically. Researchers often adopt Markov Chains to the problem – as it helps to eliminate the impact of the past system states on the future states. Nevertheless the application of this method is often connected with some assumptions. For example, it is often assumed that the lead time equals zero, which is not common situation in real life. It should be mentioned that theory of stochastic processes generally and Markov Chains in particular require special knowledge in corresponding mathematical fields.

This fact leads to the popularity of deteriorating stock management problem among operation research specialists. A lot of works, devoted to the problem, can be found in the European Journal of Operation Research. The most extensive reviews of major tendencies in scientific analysis of the problem are presented in the journal. Among these publications the research of Bakker et al (Bakker, Riezebos, & Teunter, 2011) should be mentioned. It continues the review of S.K. Goyal and B.C. Giri (Goyal & Giri, 2001). More than three hundreds scientific articles for the period 1990 – 2011 were analyzed with classification in these two review articles.

In many practical models where lead time is greater than zero, strict mathematical solution is not defined. In this case some approximate solutions or heuristics are used. Heuristics are usually implemented with the use of high level programming languages. Sometimes additional statistic analysis is performed, for example, at van Donselaar (van Donselaar & Broekmeulen, 2012), Z. Lian and L. Liu (Lian & Liu, 2000).

The present research is concentrated on applied statement of deteriorating stock problem. We examine the model which has restrictions imposed both by manufacturer and two distribution channels. The channels have different requirements to remaining shelf life of the product. A few researches with similar model restrictions should be mentioned (all of them are based on approximate algorithms):

- Amorim et al (Amorim, Gunther, Almada-Lobo, 2012) and Yan et al (Yan, Banerjee, & Yang, 2011). There are two components of logistic system: manufacturing and distribution of deteriorating stock. The integrated form of the problem is studied.
- Schneider and Klabjan (Schneider, & Klabjan, 2013). The specifics of deteriorating stock inventory management with a few distribution channels are described. Lost sales cannot be replenished in future periods. The mathematical formulation of the problem with strict market requirements is presented.
- Shavandi et al (Shavandi, Mahlooji, & Nosratian, 2012). The multiproduct model with stochastic demand is analyzed. The products may have independent or complimentary demand or may be interchangeable products.

According to the literature review, there is no exact mathematical algorithm for the problem with the restrictions enumerated above, thus simulation is used for this research.

2. SETTINGS

2.1. The logistic system description

Configuration of the logistic network has a great impact on the approach to deteriorating products inventory management. The supply chain of juices, which are not produced from concentrate (“not from concentrate juices”), has some features related to manufacturing specifics of this juice type. The shelf life of the product is nine months. The demand for this type of juice is relatively low and this fact affects the planning process, as it will be shown below. It’s one of the reasons why manufacturing of not from concentrate juices may be often unprofitable in Russia. Companies often collaborate with the contract manufacturers (co-packers). A co-packer is a separate and independent company which often restricts possible production weeks and minimal production lot size. The co-packer optimizes its location according to his suppliers’ network, which is affected in turn by fruits’ harvesting seasonality. The lead time to ship the production from co-packer to the company may be considerable.

2.2. System restrictions

The products with relatively short shelf life can be compared with a time bomb – the interval between wrong decision in shipments planning and its consequences may amount up to six months. There are few additional constraints, which complicate the process.

2.3. Market constraints

- actual month demand value may differ from the planned value in -50% to 100% range.
- different client groups have different requirements to remaining product shelf life. Nation-wide retail networks (KA – Key Accounts) need not less than 2/3 of remaining shelf life, while traditional trade stores (TT – Traditional Trade) do with only 1/3. If the remaining shelf life is less than one third of total shelf life the product is wasted. (Fig. 1) The sales balance between these two channels (KA/TT) may vary from 75/25 to 90/10. Current remaining shelf life allocation of the stock is very important in the planning process. Shortage of the product, which is acceptable for shipment to retail networks, may lead to high penalties and to loss of important distribution network component owing to frequency of such situations.

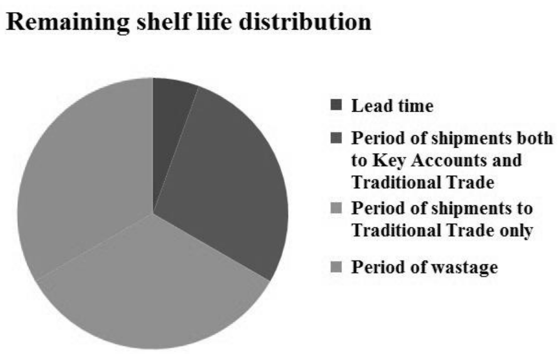

Fig. 1 Remaining shelf life disribution by periods

2.4. Manufacturer's constraints

- minimum production lot size (batch). "Production lot size/planned demand" ratio is very important. If the batch is bigger than the demand for 2,5 months then even slight decrease of actual demand value will increase the risk of wastage significantly.

- the restriction of possible production periods. The manufacturer may produce on certain weeks with set interval between production weeks only.
- time span between order placing and manufacturing. The order should be placed several weeks in advance before the production. The planning period may vary from 2 to 7 weeks depending on the manufacturer. It should be mentioned that situation with stock may change significantly during this planning period.

2.5. Limitations set by company's business processes

- warehouse management system (WMS). The FEFO (First Expired – First Out) rule is applied to shipments in both distribution channels. The requirements to remaining shelf life are set for each client. Deployment is not possible in case there is no stock which satisfies remaining shelf life limitation. For example, a batch with 64% remaining shelf life cannot be shipped but the difference to limit value of 66% is 2% only (approximately 5 days).
- sales plan change. Month sales plan may vary within significant range – up to 40%.
- company's marketing policy. Certain possible ways to reduce shortages may be hindered by marketing policy regarding demand stimulation.

2.6. Initial planning algorithm

A special Excel-based planning tool is used for order placing and stock level control. The inventory level should be not less than 25 days of stock and does not exceed 57 days of stock limitation. These values were set heuristically.

Initial algorithm considers only a few of system's restrictions: manufacturer's production weeks, minimal production lot size and forecasted sales before shipment date. The planning tool cannot trace remaining shelf life of the stock and stock structure. Despite these facts this planning tool is sufficient if sales plans are much greater than minimal production lot size. In this case the wastage risk declines significantly.

The situation when relatively big batch of product has a remaining shelf life not suitable for key accounts sales occurs occasionally. In this instance the batch will be written off owing to the fact that traditional trade share is less than 25%, and only a part of it will be sold.

2.7. Improving of shipments planning

The methods for write-offs forecasting and shipments planning are studied in the practical part of present article.

Research goals:

- development of wastage level forecasting algorithm;
- development of more advanced planning tool;
- development of stock remaining shelf life monitoring means;
- improvement of coordination between planning and marketing departments.

2.8. Primary problem analysis

Write-off risks are evaluated at tactical and operational level. At first the annual plan is analyzed, as it helps to find initial wastage value estimate. In turn it can be used as a benchmark value later as well as for justifying the problem's importance. There are a few algorithms which can be applied. The one, which was chosen, has rather good "complexity/accuracy" ratio and is suitable for quick estimation. The algorithm takes into account seasonality of sales, which increases both the wastage and OOS (Out Of Stock) values.

The economic order formulae is not suitable for the system in current configuration since the minimal quantity of shipments (orders) is restricted by the key accounts service level (there should always be the stock suitable for sales to them). Thereby order costs and warehouse costs are not taken in consideration in the optimization algorithm.

The integer optimization model was developed in the Excel. The model was used for wastage level calculation and estimation of the demand fluctuations effect on it. The exact dates when the write-offs take place are not important.

Model assumptions:

- two weeks of the stock shelf life pass since production when the order is shipped to company's warehouse;
- there is set safety stock level;
- there is set KA/TT sales ratio;
- the maximum interval between two shipments cannot be more than 75 days (otherwise shortage of products for KA will be inevitable);
- annual seasonality doesn't depend on absolute demand value.

If there is an order shipment for a month (this event is determined by integer variable), then the amount of wastage is calculated by formula (1):

$$\sum_{j=1}^{n}\sum_{i}^{12} W_{i,j} = z \bullet \left(\left(\frac{D_{j,i}^{ka} + D_{j,i+1}^{ka} + D_{j,i+2}^{ka}}{3} - LimitKa + MinStock \right) \bullet \frac{\left(S_{j,i} + S_{j,i+1} + S_{j,i+2}\right)}{3} - \left(S_{j,i+3} + S_{j,i+4} + S_{j,i+5}\right) \bullet l \right)$$

$$i \in (1;12) \qquad (1)$$

$$z \in \mathrm{int}$$

This expression describes two phases of stock shelf life.

$D_{j,i}^{ka}$ – minimal production lot size of product *j*, expressed in days of stock for a period i when the stock can be sold to key accounts *ka*

LimitKA –time interval length of key account sales (75 days);

MinStock – minimal stock (25 days);

S_{ij} – average sales of product j for a period i ;

l – share of key accounts sales.

The difference between two periods with can't be greater than 3 for each product *j*.

The target function (2) is wastage minimization:

$$\sum_{j=1} W_j \to \min \qquad (2)$$

The scenario analysis was performed. The best periods for order placing were found with the Solver in Excel. The results are presented in Table 1.

Table 1 Experiments' results

Sales plan fulfillment, %	**Wastage for one year period, litres**					
	Minimal safety stock level					
	25			20		
	Shipments TT, %			Shipments TT, %		
	10	15	20	10	15	20
80	116177	100932	83422	88048	77303	62674
90	87743	73563	63006	68927	63546	53360
100	69878	57960	43669	54463	43206	33729
110	52559	40161	30355	39010	31082	21210
120	42428	30613	18305	27114	18989	10224
130	26581	17788	9213	16425	8141	2910
140	21351	9674	2571	8920	2834	1532
150	10860	2934	1346	3129	1803	255

Thus the extension of traditional trade distribution channel has a positive effect on wastage risk elimination. Comparable result can be achieved by lowering of safety stock level. The decrease of the system "robustness" helps to cut wastage percent. The five days of safety stock level difference is important in such situation. So, the problem of finding the balance between wastage and out of stock arises. The system is very sensitive to the sales plan decrease.

There was performed an experiment to estimate the demand seasonality impact on write-offs level. Without demand unevenness the forecasted wastage will be

66384 liters, the difference with the base system version will be 5%. But in case of the most pessimistic scenario the difference will be 12%. If the product has low marginal costs the profit level may vary by several times.

The analysis helps to get the general perspective of expected financial results but is not sufficient for all research goals. If current (initial) planning algorithm is kept the wastage level will be higher than possible value because it doesn't take into account stock distribution changes over time. The planning algorithm should be reengineered. So the description of the updated planning tool is presented in the next part of the article.

2.9. Operational planning algorithm development and application

To achieve better shipment planning accuracy more valid inventory movement model is required. The stock distribution between customers' groups should be calculated for each planning day. There are only a few rules of inventory management in the system, some of them are automated, thus the development of the new planning tool is adequate to the research goal.

The source of the data (the input for the model) is a spreadsheet exported from the ERP (Enterprise Resource Planning) system.

The algorithm should estimate the product demand for each distribution channel, choose the batch of stock by FEFO policy and then should minus the stock level by demand value consequently for each period. If the batch is lower than the demand the next appropriate batch is chosen by FEFO rule. Standard Excel formulas cannot be used to describe this logic. For this reason there was built and implemented the VBA-based (Visual Basic for Applications) deterministic discrete-event simulation model for the planning tool. The model considers not only current stock but future shipments too (and the expected production date of these product batches). The forecasting horizon is 105 days due to the fact that the quarter year sales plan is used.

The sequence of algorithm operation steps for each planning period for each product SKU:

1) Selecting of the date;
2) Calculation of date "borders" for each shipment group;
3) Checking the future shipments arrival;
4) Stock sorting (by production date);
5) Selecting and processing batches for key accounts with FEFO policy;
6) Selecting and processing batches for traditional trade with FEFO policy;
7) Stock level update.

The algorithm considers that the stock suitable for key accounts can be shipped to traditional trade while the reverse situation is not acceptable. The data calculated for each planning period is used to estimate approximate dates of each batch moving from one stock group to another (in case the batch is not sold completely before this moment). The stock is calculated both in units and days.

The image below (Fig. 2) represents the part of the planning tool interface. The date of calculation is 21st February 2013. The month sales plans and some additional data are not shown. The possible order point is the end of march. The most important indicators are presented for four analyzed products:

Planned future shipments – the already placed orders with the quantity in thousands of units shown (blue);

Total stock – total stock forecast expressed in days.

The following fields were not presented in the initial planning tool:

Stock for KA – stock suitable for key accounts shipment, days;

Stock for TT – stock suitable for traditional trade shipments only, days;

Wastage risks – expected dates of product write-offs.

The stock distribution by customers' groups is added too. The closer this parameter to 100% is, the less system is vulnerable to wastage risks for ongoing months.

We can see that, when the shipment of the Product 3 arrives on 2nd April, the stock suitable for KA shipments will be 12 days only, but the total stock will be 42 days of stock. It's likely that the order would not be placed in the initial version of the planning tool, which would lead to out of stock risks for key accounts. It can be seen that on 24th March there will be 1200 units of the product wasted. So there is a month of time to find possible ways to outrun this write-off. Implementing of additional "modules" to the planning tool helps to plan in more precise way – all possible risks of wastage and out of stock are traced and more detailed information of current system state is given.

The stock movement graph for Product 3 is given on the Figure 3. The green fill shows that the batch is suitable for KA, no fill is for TT batches only and orange fill is for wasted products. The expected "lifecycle" of each batch can be traced.

The weekly analytical report is formed with the help of the planning tool data. The report helps to initiate preventive measures to minimize wastage for ongoing three months. Right time informing is a crucial factor for write-offs elimination and is one of the responsibilities of planning and analytical department. The report is made in "dashboard" style which is common in KPI monitoring applications and is used as a decision support tool.

The new planning tool was implemented in the planning business process for all not concentrate juice manufacturers and proved its superiority against the older version of the tool.

C	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI
80%	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
Start	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4
	18.03.2013	19.03.2013	20.03.2013	21.03.2013	22.03.2013	23.03.2013	24.03.2013	25.03.2013	26.03.2013	27.03.2013	28.03.2013	29.03.2013	30.03.2013	31.03.2013	01.04.2013	02.04.2013	03.04.2013	04.04.2013	05.04.2013
	Future shipments																		
Product 1									17							10			
Product 2									17										
Product 3																10			
Product 4																14			
	Total stock (days)																		
Product 1	34	33	32	31	30	29	28	27	49	48	47	46	45	44	47	60	59	58	57
Product 2	46	45	44	43	42	41	40	39	62	61	60	59	58	57	61	60	59	58	57
Product 3	57	56	55	54	53	52	51	50	49	48	47	46	45	44	47	93	92	91	90
Product 4	44	43	42	41	40	39	38	37	36	35	34	33	32	31	33	49	48	47	46
	Key Account Stock																		
Product 1	36	35	34	33	32	31	30	29	56	55	54	53	52	51	55	72	71	69	68
Product 2	53	52	51	50	49	48	43	42	71	70	69	68	67	66	71	70	69	68	67
Product 3	25	24	23	22	21	20	19	18	17	16	15	14	13	12	12	58	57	56	55
Product 4	55	54	53	51	50	49	48	46	45	44	43	41	40	39	41	61	60	59	57
	Traditional Trade Stock																		
	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	0	0	0	0
	14	13	12	11	10	9	26	25	24	23	22	21	20	19	20	19	18	17	16
	184	183	182	181	180	179	156	155	154	153	152	151	150	149	162	161	160	159	158
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wastage risks																		
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	1 268	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Stock distribution (KA/total)																		
	91%	91%	92%	92%	93%	93%	94%	94%	97%	98%	98%	98%	99%	99%	100%	100%	100%	100%	100%
	94%	94%	94%	95%	95%	96%	87%	87%	92%	92%	93%	93%	93%	93%	93%	94%	94%	94%	94%
	35%	35%	34%	33%	32%	31%	33%	32%	31%	30%	29%	27%	26%	25%	23%	59%	59%	59%	58%
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Fig. 2 Planning tool interface

B	C	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU
		18.03.2013	19.03.2013	20.03.2013	21.03.2013	22.03.2013	23.03.2013	24.03.2013	25.03.2013	26.03.2013	27.03.2013	28.03.2013	29.03.2013	30.03.2013	31.03.2013	01.04.2013	02.04.2013	03.04.2013	04.04.2013	05.04.2013
Product 3	28.02.2013	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102	102
Product 3	29.05.2013	5449	5449	5449	5449	5449	5449	5449	5449	5449	5449	5449	5449	5449	5449	5449	5449	5449	5449	5449
Product 3	24.06.2013	981	924	866	808	750	692	692	692	692	692	692	692	692	692	692	692	692	692	692
Product 3	24.06.2013	576	576	576	576	576	576	576	576	576	576	576	576	576	576	576	576	576	576	576
Product 3	13.08.2013	1962	1962	1962	1962	1962	1962	1904	1846	1789	1731	1673	1615	1557	1500	1446	1393	1340	1287	1234
Product 3	29.08.2013	7141	7141	7141	7141	7141	7141	7141	7141	7141	7141	7141	7141	7141	7141	7141	7141	7141	7141	7141
Product 3	04.11.2013	5838	5607	5375	5144	4913	4682	4450	4219	3988	3757	3525	3294	3063	2832	2619	2407	2194	1982	1769
Product 3	12.12.2013																10000	10000	10000	10000
Product 3	16.01.2014																			

Fig. 3 FEFO stock movement graph

3. CONCLUSION

The next research stage is the development of a detailed simulation model of stock movement in more suitable simulation environment than VBA. There is a simulation model developed in AnyLogic 6.7 University environment (www.runthemodel.com). It can be run online (requires installed java-machine to run in a web browser), some system parameters can be changed during the simulation. The detailed simulation study of the model performance is beyond the scope of the article.

To conclude with, this article covers the problem of inventory management for deteriorating products. The wastage minimization problem was formulated taking into account restrictions common for not concentrate juice supply chain. The restriction's impact on the system performance is studied. The modification of a standard planning tool in order to accommodate the challenges of deteriorating stock planning is presented. The proposed approach can be applied to a wide range of similar products. The computer simulation methods applied to the planning of such product type helped to lower wastage and out of stock costs as well as to improve coordination between marketing and planning departments.

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