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DEVELOPMENT OF DECISION-SUPPORT ALGORITHMS FOR COMMODITY MANAGEMENT

Abstract. The purpose of this paper is to improve the commodity management of retail chains by developing theoretical provisions of decision support system of retail chain commodity management (DSS RCM). Trading networks buy goods directly from manufacturers or large wholesalers, place these goods in warehouses, organize their distribution to stores. Commodity managers should decide how to provide all stores of the network in timely manner with the most profitable product every day.

The objective of the DSS RCM is to maximize the daily trading margin, per each euro invested in commodities taking into account restrictions on commodity resources and shelf space. The DSS RCM have to prepare bills of lading and orders for inbound logistics, distribution and re-distribution of commodities within the network. Decision support uses data available in any retail software. The calculation algorithms are simple and effective to ensure the necessary and sufficient accuracy with the time and hardware limitations and without significant investments in hardware and staff qualifications update. Algorithms calculate the optimal solution based on the objective function (for example, profit maximization) and restrictions (for example, inventory level, store sales, profit from sales of a given product).

The paper systematized the approaches of other scientists to solve the problem of product management in retail. Author analyze the strengths and weaknesses of those approaches for purpose to find the optimal approach for retail chains.

So the aim of this study is to develop theoretical basis of decision support system of retail chain commodity management (DSS RCM). The proposed method of optimization of commodity assets in retail based on their mathematical modeling and calculating of the consolidated profitability ratio. Research results are limited to homogeneous product retail chains (e.g., clothing or footwear).

By using proposed algorithms calculations could be in real-time mode in the database for tens (hundreds) of thousands items in the product range (for example, when selling clothes and shoes, a unique combination of model, color and size forms a separate item in the product range) in hundreds (thousands) of stores. Therefore, it could be hundreds of millions of combinations items-stores (Big Data).

***Keywords*:** retail chain, commodity management, decision support, sales analytics.
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РОЗРОБЛЕННЯ АЛГОРИТМІВ ПІДТРИМКИ УХВАЛЕННЯ РІШЕНЬ ЩОДО УПРАВЛІННЯ ТОВАРНИМ АСОРТИМЕНТОМ

Анотація. Завдання нашої роботи — вдосконалення товарного менеджменту роздрібних мереж шляхом розроблення теоретичних положень системи підтримки ухвалення рішень щодо управління товарним асортиментом роздрібної мережі (DSS RCM). Торговельні мережі купують товари безпосередньо у виробників або значних гуртовиків, розміщують ці товари на складах, організовують їх поширення в магазини. Товарні менеджери повинні вирішувати, як забезпечити всі магазини мережі вчасно найприбутковішим продуктом кожного дня.

Завдання DSS RCM полягає в тому, щоб максимізувати щоденну маржу торгів на кожен євро, вкладений у товари, з урахуванням обмежень на товарні ресурси і шельфовий простір. DSS RCM має підготувати коносаменти і замовлення на вхідну логістику, розподіл і перерозподіл товарів у межах мережі. Підтримка ухвалення рішень використовує дані, доступні для будь-якого роздрібного програмного забезпечення. Алгоритми розрахунку прості та ефективні для забезпечення потрібної та достатньої точності з обмеженнями часу та апаратних засобів і без значних інвестицій в оновлення апаратних засобів та кваліфікації персоналу. Алгоритми обчислюють оптимальне рішення на основі цільової функції (наприклад, максимізації прибутку) і обмежень (наприклад, рівень запасів, продажі магазинів, прибуток від реалізації конкретного товару).

Систематизовано підходи інших учених щодо розв'язання проблеми управління продукцією в роздрібній торгівлі. Проаналізовано сильні і слабкі сторони цих підходів з метою пошуку оптимального підходу для роздрібних мереж.

Тому метою нашого дослідження є розроблення теоретичної основи системи підтримки ухвалення рішень щодо управління роздрібними товарами (DSS RCM). Запропоновано спосіб оптимізації товарних активів у роздрібній торгівлі на основі їхнього математичного моделювання і розрахунку консолідованого коефіцієнта прибутковості. Результати досліджень обмежуються однорідними роздрібними мережами (наприклад, одягом або взуттям).

За допомогою запропонованих алгоритмів розрахунки можна здійснювати в режимі реального часу в базі даних для десятків (сотень) тисяч позицій в асортименті (наприклад, при продажу одягу та взуття, унікальне поєднання моделі, кольору і розміру утворює окремий елемент в асортименті) у сотнях (тисячах) магазинів. Тому це можуть бути сотні мільйонів комбінацій предметів-магазинів (Big Data).

Ключові слова: роздрібна мережа, управління товарним асортиментом, підтримка ухвалення рішень, аналіз даних продажів.

Формул: 9; рис.: 0; табл.: 1; бібл.: 39.

1. Introduction. A key problem is the timely provision of stores with the most profitable products (task of optimization of assortment). Due to score of operations it is possible only with automatic DSS RCM [1, p. 117—135]. However, one of the barriers of practical application: «the current literature lacks not only information on the comprehensive structure of the decision problem, but also a decision support system that can be directly applied to practice in a straightforward manner» [2, p. 808].

2. Literature review and the problem statement. Various authors emphasize factors that drive decision-making in retail commodity distribution: Product, Demand, Service level and Logistics costs (*Table*).

Table

The main factors that drive decision-making in retail commodity distribution and their applicability to the study

Factor		Authors	Possibility of practical application	Applicability to the study
Product	Product range characteristics	Blackburn, 1991; Chopra, 2003; Christopher, 2011; Hunter et al., 1991; Iurasov, 1998; Kunz and Rupe, 1999; Miller et al., 2010; Nuttle et al., 1991	Quantitative characteristics directly related to SKU are easy to take into account and process	Used in presented model through trade margin and turnover ratio, forming profitability ratio
	shelf-space allocation approach	Chong et al., 2001; Griswold, 2007; Hübner, 2011; Hübner and Kuhn, 2012; Hübner and Schaal, 2012; Hübner, Kuhn and Wollenburg, 2016; Irion et al., 2012; Kök and Fisher, 2007; Kuhn and Sternbeck, 2013; Suárez, 2005; Yücel et al., 2009	Applicable for homogeneous products, e.g. clothing or footwear. Difficult to implement when products have varying sizes and other placement conditions	Could be used by setting limit for common number of goods in store
	Interdependencies between products	Honhon and Seshadri, 2013; Hübner and Kuhn, 2012; Hübner, Kühn and Kuhn, 2016; Hübner, Kuhn, and Wollenburg, 2016; Kök and Fisher, 2007; van Woensel et al., 2007; Xin et al., 2009; Yücel et al., 2009	Difficult to implement when products have varying prices, costs, trade margins, demands, turnover ratio or order quantities. Difficult to measure objectively interdependencies between different products. Require exhaustive data as well as sophisticated modeling that may interfere the practical application	Not used
Demand	Demand pattern	Chhetri et al., 2017; Iurasov, 1998; Kotzab, 1999	Quantitative characteristics directly related to SKU are easy to take into account and process	Used in presented model through sales and stock data
	Demand preferences	Boyd and Bahn, 2009; Chernev, 2003; Deng and Kahn, 2009; Miller et al., 2010; Simonson, 1999	It is difficult to control dynamically changing patterns of customers' decision-making	Partly used in presented model by maintaining sufficient inventory level based on sales data (reflected previous consumer buying preferences)
	Trade-off	Hübner, 2017	It is difficult for retail chains to define such parameters for each from tens of thousands items	Not used
Service level		Broniarczyk, Hoyer and McAlister, 1998; Chernev and Hamilton, 2009; Christopher, 2011; Dhar et al. 2001; Hoch et al., 1999; Korpela et al., 2001; Kotzab, 1999; Krishnan, Koelemeijer and Rao, 2002; Meixell and Gargeya, 2005	Assortment range characteristics as well as Availability of different types of products is easy to control automatically. Other characteristics needs formalization in IT-system	Used in presented model by maintaining sufficient inventory level for most profitable commodities in stores and DC(s)
Logistics costs		Meixell and Gargeya, 2005; Ashayeri and Rongen, 1997; Chuang, 2002	Easy to calculate and operate	Not used

Source: compiled by the authors on the basis of analysis [1—39].

The list of factors based on literature review:

1. Factor of Product consists of 3 types:

– Product range characteristics: Entire product range characteristics; Product value density;

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Packaging density; Turnover; Share of total assortment sales; Cash-flow; Trade margin; Adjusted gross margin; Profitability ratio; Percent gross margin return on inventory; Mark-down percentage, Sales per square meter;

– Shelf-space allocation approach: Is it fit to limited shelf space, Gross margin return on space;

– Interdependencies between products: Interdependencies between products of same assortment category or cluster; Could be substituted or substitute for other traded goods

2. Factor of Demand consists of:

– Demand pattern: Demand volume; Demand volatility; Spatial demand pattern;

– Demand preferences: Specifics of customers' decision-making; Same-store sales;

– Trade-off between shortage costs for unsatisfied demand and salvage value for unsold goods.

3. Service level can be described using characteristics such as: Flexibility; Responsiveness; Multiple quality levels; Assortment range; Availability of favorite brands, national brands and new products.

4. Logistic costs consists of: Transport costs; Warehousing costs; Inventory costs/

Logistic costs can't be applicable to the study because we rely on existing network of routes of distribution, cost per unit distance marginalized through achieving economies of scale and warehousing costs are similar for homogeneous products.

Therefore, it is more cost effective to construct a system for maintaining of optimal level of inventory, based only on real-time sales and stock data.

Hence, having relatively constant prices (the firm does not have the opportunity to change them every day) and relatively insignificant transportation costs, commodity stocks can be distributed from DC(s) to stores and redistributed between stores in accordance with the criterion of maximizing the daily volume of trade margin, per each euro invested in goods.

This approach should be applied to the inbound logistics, with the only difference that the speed of commodity turnover (liquidity) and trade margins analyzed in general throughout the retail chain (not for individual stores).

Thus, all activities of the retail chain for the physical distribution of goods can be subordinated to the goal of obtaining the maximum margin from the capital invested in the commodity. This approach is consistent with the principle of calculation of profitability. In this article, we are interested in the return on capital invested in inventory.

There are a lot of algorithms and models for optimization of commodities flows in retail, some of them dedicated to reverse logistics processes, some oriented on infrequently purchased products, such as consumer electronics, appliances and home furnishings [8, p. 159—171] and other oriented to supply chain planning in grocery retail, identifies retail demand and supply chain planning problems and declares further research opportunities: creation of DSS for demand forecasting and assortment planning [15, p. 228—247].

Consequently, we need to produce practically oriented model for frequently purchased products, when consumer preferences repeatedly influence the sales. E.g. consumers frequently buy the same food products and adults buy the same size footwear. We cannot rely on already created systems (e.g. «Sourcing Simulator» for apparel retail model [7, p. 118—125; 9, p. 247—259; 3, p. 97—134]) since their algorithms are closed and inaccessible for modernization.

3. Research results. To allocate total resources Q (all commodity assets of the retail chain) means to assign to each of the participants «j» (retail store) of physical distribution a certain set of goods x_j in such a way that the sum of the distributed goods coincides with their quantity available:

$$Q = x_0 + \ldots + x_L = \sum_{j=0}^{L} x_j . \quad (1)$$

A vector $X = (x_0, ..., x_L)$ from the space R_L+ is called the distribution, if satisfied the condition (1), then the distribution is acceptable. In the retail commodity management system x_0 is the vector of reserves of the *DC*(*s*), and x_j ($j = \overline{1; L}$) — vectors of trading stock in retail chain (stores). Since the article does not set the task of more rational distribution of goods in warehouses, it is advisable to combine all stocks in one indicator.

It should be noted that distribution indicates for each of the *L* participants the amount of each of the M products that it will get.

Thus, distribution assigns to each of its participants a set of products. In order to find optimal distribution, it is necessary to form an objective function *f*(*x*) (Iurasov, 1998):

$$f(x) = \sum_{j=1}^{l} \sum_{i=0}^{m} (x_j^i \cdot Cpr_j^i) \to \max, \tag{2}$$

where Cpr_j^i is coefficient expressing profitability of trade by the commodity «*i*» in the store «*j*». Later, we will determine an algorithm for calculating it.

One of the limitations is the restriction on the used commodity resources:

$$\sum_{j=0}^{l} \sum_{i=0}^{m} x_j^i = Q. \tag{3}$$

Other restrictions are related to:

– the need to accelerate sales of goods with expiring shelf life. The given goods should be distributed not where it is sold at the highest profit, but where the probability of its sale is higher;

– irrationality of distribution of all commodity stocks in shops of a retail chain. Stores sell a particular quantity of goods between regular supply from the DC(s). If the inventory of stores will significantly exceed this amount, then commodity turnover T_j^i, and therefore Cpr_j^i, will begin to decline, and storage costs will grow.

$$\begin{gathered} If(Ex_j^i \le x_j^i / \overline{S}_j^i), \\ \{x_j^i \le (Ex_j^i - 1) * \overline{S}_j^i\} \\ Else(If(1 < Sr_j * \overline{S}_j^i) \\ \{x_j^i = Sr_j * \overline{S}_j^i\} \\ Else(If(1 \ge Sr_j * \overline{S}_j^i) \\ \{x_j^i = 1\})), j = \overline{1; l}, i = \overline{0; m}, \end{gathered} \tag{4}$$

where Ex_j^i — the period of sale of the goods before the expiration of its shelf life in days;

$\overline{S}_j^i$ — the average sales volume of the commodity «*i*» in the store «*j*»;

Sr_j — stock ratio of one of the company's stores.

Sr_j varies depending on the situation, and should be higher in stationary, permanent shops than in temporary (trays, tents). In the simplest case, Sr_j slightly exceeds the number of days between regular shipments to store «*j*», insuring against shortages of goods during the activation of demand.

The economic meaning of the first condition ($Ex_j^i \le x_j^i / \overline{S}_j^i$) is that stocks of goods with expiring shelf life should not exceed the average level of its sale for the number of days remaining before expiration.

The economic meaning of the second condition ($1 < Sr_j \cdot \overline{S}_j^i$) is to maintain a certain level of inventory. This level depends directly on the level of sales. Specifying condition: ($1 \ge Sr_j \cdot \overline{S}_j^i$), indicates that even if this shop sells, on average, less than one product for the period between regular deliveries, it is still desirable to hold at least 1 copy of the product there.

To take into account limited shelf space it is possible to set the upper limit for number of goods in store (applicable for homogeneous products).

$$\sum_{i=0}^{m} x_j^i \le S\max_j, \tag{5}$$

where $S\max_j$ — the upper limit for number of goods in store.

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To analyze inventory liquidity, we use the coefficient of commodity turnover. It can be calculated as the ratio of sales of goods per day, minus twice the number of returns of defective goods per day and minus the number of decommissioned goods with expired shelf life per day to the balance at the beginning of the day and the receipt of the product per day.

$$T_j^{\,i} = (S_j^{\,i} - 2D_j^{\,i} - Ex_j^{\,i}) / (G_j^{\,i} + In_j^{\,i} + Out_j^{\,i}), \tag{6}$$

where S_j^i — the quantity of commodity «*i*» sold per day through the store «*j*»;

D_j^i — the quantity of defective commodity «*i*» returned per day to store «*j*» and subject to decommission;

Ex_j^i — the quantity of the commodity «*i*» in the store «*j*» that is to be written off, due to the expiry date;

G_j^i — the remnants of the commodity «*i*», at the beginning of the trading day, in the store «*j*»;

In_j^i — the quantity of commodity «*i*» received per day in the store «*j*».

Out_j^i — the quantity of commodity «*i*» dispatched per day from the store «*j*» to DC(c) or other stores.

The economic sense of subtraction of the doubled number of the returned commodity is that these goods have already been accounted for as sold. The operation of returning a defective product entails a refund of money to the buyer (the first source of losses of the retail chain), and then write-off of defective goods (the second source of loss of the retail chain).

In order to take into account the dynamics of changes in the turnover of goods, we will create a consolidated coefficient of commodity turnover; it should give an information on the demand for this product, not only during the last trading day, but also for the whole period of sale of the goods.

Values of commodity turnover of different trading days are important in an unequal degree: the most important is the turnover of the last trading day, it reflects the latest changes in consumer tastes and preferences; followed by the commodity turnover of the previous day and so on.

To take into account their importance, it is possible to use a number of mathematical methods. In the simplest case, we apply an arithmetic progression with multipliers *M*0 and *M*1. In sum, they should form a unit (1):

$$M0 + M1 = 1.$$

For a dynamically changing consumer market, it is advisable to use the *M*0 in the range of 0.05—0.2. If *M*0 = 0.1, the value of the Consolidated turnover ratio is 10 % due to the value of the turnover ratio of the last trading day and 90 % due to the value of the coefficients of the remaining days (9% of which will be on the penultimate day, and so on). Thus, it turns out that the values of the coefficients of the last week of trade will prevail in the value of the Consolidated turnover ratio (52.17%).

The exception to this rule is the moment of the first appearance of the goods in the store, in this case the consolidated coefficient of commodity turnover immediately assumes the value of the coefficient of commodity turnover for the first-day of trade. Thus, the determination of the consolidated turnover ratio has an autoregressive form:

$$^{first}Ct_j^i = T^i{}_j$$

$$^{cur}Ct_j^i = {}^{prev}Ct_j^i \cdot M1 + T^i{}_j \cdot M0\,, \tag{7}$$

where $^{first}Ct_j^i$ — the consolidated coefficient of commodity turnover of the first day of trade of commodity «*i*» in the store «*j*» (it is assumed that previously we did not sell such product in the store);

${}^{cur}Ct_j^i$ — the consolidated coefficient of commodity turnover of the last (current) day of trade of commodity «*i*» in the store «*j*»;

${}^{prev}Ct_j^i$ — the consolidated coefficient of commodity turnover of the penultimate day of trade of commodity «*i*» in the store «*j*».

It is important to note that the values of commodity turnover coefficients are not sufficient to make a final conclusion on most profitable placement of commodity. Aside from consideration is the value of the trade margin of commodity in this store.

Trade margin actively used for optimizing retail assortment in the model of Miller et al., (2010). The proposed model oriented on infrequently purchased products, such as consumer electronics, appliances and home furnishings. However, in the model (Miller et al., 2010) used other characteristics:

- the expected utility of customer *i* for product *j*;
- the additional value that customer *i* receives due to purchasing from retailer ρ;
- utility thresholds, etc.

Such characteristics difficult to measure objectively for each from tens of thousands items of retail chain. This is why we need to produce new model for frequently purchased products, when consumer preferences repeatedly influence the sales. E.g. consumers frequently buy the same food products and adults buy the same size footwear.

The multiplication of the coefficient of commodity turnover with the margin gives a coefficient of profitability from the trade by this commodity in this store. The economic meaning of this coefficient is the reflection of the speed at which the euro invested in goods will return a euro of trade margin (% margin return on inventory investment). Since the time unit for analyzing of trading process is one trading day (analysis within the trading day is impractical, because the delivery of goods is carried out discretely and planned before the start of the trading day), it is possible to determine this coefficient as the daily volume of trading margin attributable to the euro invested in inventory.

$$Pr^i_j = M^i_j \cdot T^i_j, \tag{8}$$

where Pr^i_j — coefficient of profitability from trade by commodity «*i*» in the store «*j*»,

M^i_j — trade margin for commodity «*i*» in the store «*j*».

To reflect the dynamics of changes of the coefficient of profitability, we will create a consolidated coefficient of profitability (Cpr_j^i), the rules for it calculating are similar to the rules for calculating a consolidated coefficient of commodity turnover. Cpr_j^i reflects the dynamics of profitability (taking into account the time significance). Cpr_j^i is the main object of analysis of the DSS RCM.

The definition of Cpr_j^i has an autoregressive form:

$$\begin{gathered} {}^{first}Cpr_j^i = Pr^i{}_j \\ {}^{cur}Cpr_j^i = {}^{prev}Cpr_j^i \cdot M1 + Pr^i{}_j \cdot M0, \end{gathered} \tag{9}$$

where ${}^{first}Cpr_j^i$ — the consolidated coefficient of profitability of the first day of trade of commodity «*i*» in the store «*j*» (it is assumed that previously we did not sell such product in the store);

${}^{cur}Cpr_j^i$ — the consolidated coefficient of profitability of the last (current) day of trade of commodity «*i*» in the store «*j*»;

${}^{prev}Cpr_j^i$ — the consolidated factor of profitability of the penultimate day of trade of commodity «*i*» in the store «*j*».

On the basis of the algorithm described above, operates the mechanism of self-regulation of the system for retail commodity management. The principle of self-regulation: a fall in the level of

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commodity stocks increases the coefficients of commodity turnover (see Equation 6), consolidated turnover (see Equation 7), profitability (see Equation 8) and the consolidated coefficient of profitability (see Equation 9) of this commodity.

As a result, the DSS RCM sends to the store (or to the company, when it comes to the inbound logistics) the commodity flow. This leads to an increase in the level of commodity stocks and drop in the coefficients of commodity turnover, consolidated commodity turnover, profitability and the consolidated profitability.

4. Conclusions. Presented theoretical provisions of decision making support for commodity management of retail chains uses existing data sets (data on trade margins, stocks, sales, etc.). It applicable for homogeneous product range. The algorithms of DSS RCM are simple and effective in order to provide the necessary and sufficient accuracy with the available time and hardware limitations. Retail chains do not require significant investments in hardware and staff qualification update for applying the presented algorithms.

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