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MULTICRITERIA INVENTORY MODEL FOR SPARE PARTS

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Preliminary notes

Inventory control of spare parts is essential to many organizations. Excess inventory leads to high holding costs and a large commitment of funds. In the other hand stock outs can have a great impact on production or service. The paper proposes a methodology for spare parts inventory control applying multicriteria inventory model. It is based on ranking and classifying the spare parts in groups according to similar attributes. Each group of spares, depending on attributes of the spares that belong to it, joins the appropriate inventory policy model and forecasting demand model.

Keywords: *inventory control, multicriteria inventory model, spare part*

Višekriterijski model skladištenja rezervnih dijelova

Prethodno priopćenje

Upravljanje skladištem rezervnih dijelova bitno je za mnoge tvrtke. Prevelika količina na zalihi vodi do velikih troškova skladištenja i velikog angažmana novčanih sredstava, a s druge strane nedostatak rezervnih dijelova na zalihi u vrijeme njihove potražnje može imati velike posljedice na proizvodnju ili usluge. Ovaj članak predlaže metodologiju upravljanja skladištem rezervnih dijelova primjenjujući višekriterijski model skladištenja. On se zasniva na rangiranju i svrstavanju rezervnih dijelova u skupine prema sličnim svojstvima. Svakoj skupini rezervnih dijelova, ovisno o karakteristikama dijelova koji joj pripadaju, pridružuje se odgovarajuća politika skladištenja te odgovarajući model predviđanja potražnje.

Ključne riječi: *rezervni dio, upravljanje skladištem, višekriterijski model skladištenja*

1 Introduction
Uvod

Efficient management of spare parts inventory is essential to many companies, those manufacturing ones (automotive, food processing, petrochemical industry, etc.) as well as those in the service sector (telecommunications, electricity, water supply, etc.). Spare parts are kept in storage to facilitate execution of maintenance functions in the event of equipment breakdowns. Although this function is well understood to maintenance managers, many companies are faced with the problem of keeping large quantities of spare parts in stock that are often outdated, resulting in unreasonably high costs of storage. Unfortunately, most maintenance managers are not interested in this issue, but are guided by the principle: "How much volume is taken from the warehouse was so ordered".

In the analysis of storage of spare parts an objective problem is in their specific, often unpredictable, nature of demand. Some spare parts have great demand, some very small (one to several years), which significantly complicates predicting the need for replacement parts.

In the management of spare parts inventory there is a need to answer the following questions:

a) **Keep each spare part in stock or not?**
Generally, a part will be stored if the benefit of current availability is greater than the cost of holding inventories. This is especially important for spares with low demand. Comparing the storage costs and the costs related to stock out at the time of the spare needs, gives the answer to this question.

b) **How many to order at once?**
When the decision has been made to stock an item, the next question to answer is how many to order at once. To determine an optimal order quantity, a well-known classical economic order quantity (EOQ) formula can be used.

c) **How many pieces to keep in stock?**
For decisions information is required on the annual demand, ordering costs and holding costs of inventory.

d) **When to release a new order?**
The moment to release a new order is usually named the re-order point. Having too many items on stock can result in high holding costs. On the other hand, having too few items on stock can result in high penalty costs. The minimum stock will be determined considering the consumption during the lead time. The user or the supplier gives the lead time, and demand is calculated based on data from the previous periods and on the basis of the known (planned) needs for spare parts.

This article tries to answer the above questions. In the literature different approaches are given to the problem of spare parts inventory.

Agrell [1] presented an interactive multicriteria framework for an inventory control decision support system. The article Multi-attribute classification method for spare parts inventory management by Braglia [2] presents a model for inventory management. Spare parts classification is defined with respect to multiple attributes (inventory constraints, costs of lost production, safety and environmental objectives, strategies of maintenance adopted). The decision diagram is integrated with a set of analytic hierarchy process models used to solve the various multi-attribute decision sub-problems.

De Almeida [3] presents multicriteria decision models for two maintenance problems: repair contract selection and spares provisioning. Two criteria (risk and cost) are combined through a multi attribute utility function in the spares provisioning decision model. Ching [4] proposed an inventory control approach called ABC-fuzzy classification, which can handle variables with either nominal or non-nominal attribute, incorporate manager's experience and judgment into inventory classification. Dekker [5] investigated demand types of spare parts and consequences of a stock out. Also, he analysed the decision rules for selection of spare parts to stock.

2
Inventory model
Model zaliha

Analyzing individual spare parts and components we may conclude that they do not have the same importance for the insurance operation of production without downtimes, for the safety of work equipment, and not even for the same amount of funds that need to be extracted for their procurement. Therefore, it is not a good solution to implement the same inventory management policy on all items in stock. Thereby, the inventory management policy means the way to determine the necessary inventory level, ordering quantity and the time of purchase. The paper proposes multicriteria inventory model which is based on ranking and classifying the spare parts in groups according to similar attributes. Each item in stock is analyzed according to certain criteria and it joins the corresponding storage policy. The criteria are:

- spare parts value-usage (affiliation with A, B, C group),
- criticality (affiliation with V, E, D group),
- frequency of demand (affiliation F, S, N group).

2.1
Ranking by value-usage
Poredak po godišnjem trošku

Every spare part in stock has a value. At the time of taking from the warehouse it becomes a cost. Value-usage is defined as a product of:

cost of an item x annual inventory demand

By analyzing the annual costs of spare parts (another time period can be taken for analysis) it may be noted that a few spare parts usually carry most of the costs.

Items are usually classified into three groups: A, B and C. Group A consists of approximately 20 % of items with 80% value-usage. It therefore represents the most significant items from the value-usage. On the other hand, group C comprises 50 % of items with only a 5 % value-usage. Group B is in the middle with 30 % items and 15 % of value-usage.

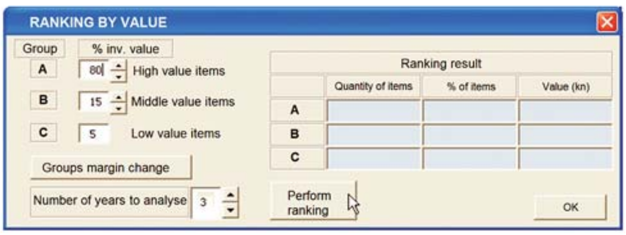

Figure 1 *Ranking by value-usage*
Slika 1. *Poredak po vrijednosti korištenja*

Labelling and determination of these three groups is arbitrary, it can be any number of groups. Likewise, the exact percentage of items in each group will vary from inventory to inventory. Important factors are the two extremes: a few items with a significant proportion of the value-usage and a large number with relatively small value-usage. The largest part of financial value stocks (80 %) can be controlled by the careful monitoring of the items of group A. For these items should be used the strict control system, which implies constant reviewing of stock levels, a small backup supply, and ordering just in time. On the other hand, for items that make up the group C should be used mild control, which allows a greater security storage and periodic review.

The concept dialog for a computer program to solve this issue is shown in Fig. 1.

2.2
Ranking by a criticality
Poredak po kritičnosti

According to this criterion spare parts and components are generally classified into three categories: Vital (group V), essential (Group E) and desirable (D group).

Parameters on the basis of which could be evaluated the criticality of spare parts are different for different activities, and the proposed mechanical parameters are shown in Fig. 2.

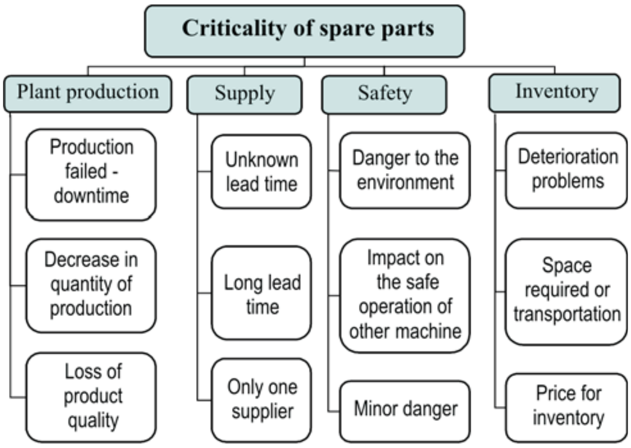

Figure 2 *Spare parts criticality*
Slika 2. *Kritičnost rezervnih dijelova*

The sub-criticality of spares regarding production, supply and safety could be described by corresponding criticality coefficients K_1, K_2 and K_3. Thereby, they can assign value 1 (for non-critical spares), 2 (for secondary critical spares) and 3 (for critical spares). Criticality regarding the storage will be explained later.

a) **The criticality regarding the production**

The basic goal of maintenance is to ensure availability and reliability of equipment to the process of production so that it could proceed continuously without delays in implementation during the planned amount of products defined by quality. All the equipment does not have the same importance for achieving this target. For example, functional failure of a specific machine will cause interruption of operation of the overall production, while the functional failure of some other machine will not significantly affect the flow of the production. For repairing one and other machine the same spare part may be needed, but the fact whether it is or is not on the stock does not have the same importance. Thus, criticality of spare part is primarily conditioned by criticality of equipment in which the spare part is used.

Some parts are installed in just one machine, and some in more machines and their criticality on this basis increased (Kranenburg [7]).

In the single part production, there is an additional problem. Depending on the type of contract, certain machine can be critical for the production, but need not be. In a certain period of time a machine can be a bottleneck of production, and therefore critical for the production, while in another period of time it may not be critical. Consequently the spares for ensuring its functionality gain or lose importance or criticality.

Equipment can be classified into three groups according to the criticality of the production: vital, essential, desirable.

Vital equipment are machines, if termination of their functions cause:

- immediate and expensive downtime,
- an unacceptable decrease in the efficiency of the entire process of production,
- an unacceptable decrease in quality of products.

Essential equipment are machines, if the interruption of their function leads to a significant loss of production, but not stopping of the entire process of production.

Desirable equipment consists of machines whose function does not have a significant impact on the quantity or quality of manufactured products. Therefore, it can allow the equipment to be some time outside the facility.

In accordance with the previously explained, the criticality of group to which the individual spare part belongs depends primarily on the criticality of the group to which the equipment belongs. As some spares can be more or less critical for the work of a specific machine their criticality level may be equal to or less than the criticality level of the machine. However, the question is in what group we should classify the spare part, if it is used in the machines that belong to different criticality groups.

For this complicated model, a possible solution is to leave management of the company the possibility to analyze such spare parts and decide on their storage policy.

For practical determination of criticality Labib [4] suggests joining criticality coefficient ranging from one to ten for the part and the machine. Common criticality of spare and the machine can be computed as

$$\sqrt{\textit{machine criticality} \times \textit{spare criticality}}$$

The resulting value can be used for determining the criticality coefficient K_1:

- for the values 1 to 3 $K_1 = 1$
- for the values 4 to 7 $K_1 = 2$
- for the values 8 to 10 $K_1 = 3$.

b) **Criticality regarding availability of purchasing**

This classification is carried out based on the lead time (LT) required to procure the spare part. For example:

K_2=3 Long lead time (more than 4 months)

K_2=2 Difficult available spares (more than 2 weeks but less than 4 months LT)

K_2=1 Easily available spares (less than a 2 weeks' LT).

c) **Criticality regarding safety**

Equipment working safety is on a high place regarding its work. If lack of spares could cause ecological disaster, danger to any people or danger to their health or the impact on the safe operation of other machines, spares are assigned the highest level of criticality (K_3 = 3). If their lack causes only the stop of functioning of the machine with little danger to the operator, spares are essential (K_3 = 2). Otherwise spares are desirable (K_3 = 1).

d) **Criticality regarding inventory**

Some spares eventually lose their quality or usability, and may be critical for storage from this point of view (in this case parameter K_4=2). If spares have large dimensions and weight they could be a problem from the viewpoint of space and transport (parameter K_4=3). In this respect if the spare is more critical it is less desirable to keep in stock. Therefore, this parameter acts contrary to the previous three regarding the level of stock. In this case the management of company has to decide on the storage policy for each such spare part.

Logical process of classifying spares in group V, E or D is displayed in Fig. 3.

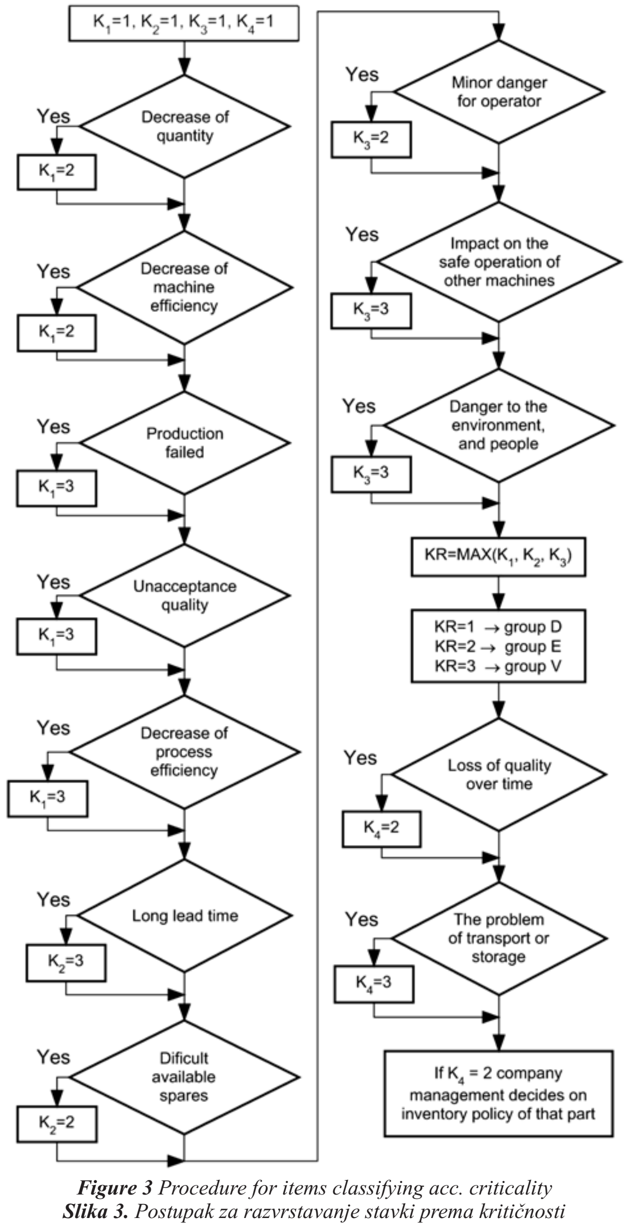

Figure 3 *Procedure for items classifying acc. criticality*
Slika 3. *Postupak za razvrstavanje stavki prema kritičnosti*

Coefficient of spare criticality (KR) is the maximum value of (K_1, K_2, K_3). If the coefficient KR is assigned the value 3, the spare is ranked in the V group; the value 2 spare is ranked in the E group; the value 1 spare is ranked in the D group.

The concept dialog for a computer program that solves this issue is shown in Fig. 4.

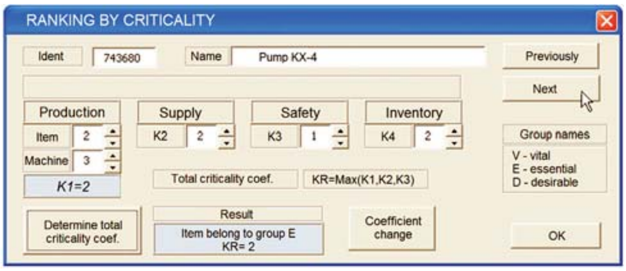

***Figure 4** Ranking by criticality*
***Slika 4.** Poredak po kritičnosti*

2.3
Ranking by frequency of demand
Poredak po učestalosti potražnje

As already stated earlier the frequency of demand plays a significant role in the selection of inventory model. As the frequency is very different, the management of spare parts will have to use different mathematical inventory models. For this purpose it is necessary to place spare parts with a similar frequency of demand in the same group. Number of groups can be arbitrary, and classification is usually performed in three groups.

The first group consists of spares which are frequently used (F-group), the second group consists of spares which are less used (S-group), and the third group consists of spares which are very rarely used (N-group). Demand for spares in this group is one piece in a few years.

Criteria for classification into these groups may be a number of spares during a certain period as recommended by Muhammad Razi [9] or the average demand during the lead time as recommended by Mukhopadhyay [10].

The concept dialog for a computer program that solves this issue is shown in Fig. 5.

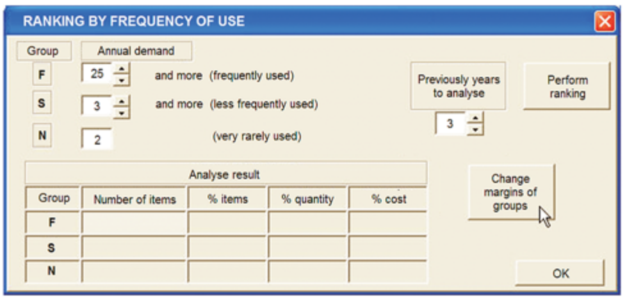

***Figure 5** Ranking by frequency of demand*
***Slika 5.** Poredak po učestalosti potražnje*

3
Associating parameters to particular spare
Pridruživanje parametara pojedinim rezervnim dijelovima

Each spare can be defined with three parameters:

(value-usage, frequency of demand, criticality)

Parameters can have three values, so the total number of possible combinations is 27:

(A,V,F)	(A,E,F)	(A,D,F)
(A,V,S)	(A,E,S)	(A,D,S)
(A,V,N)	(A,E,N)	(A,D,N)
(B,V,F)	(B,E,F)	(B,D,F)
(B,V,S)	(B,E,S)	(B,D,S)
(B,V,N)	(B,E,N)	(B,D,N)
(C,V,F)	(C,E,F)	(C,D,F)
(C,V,S)	(C,E,S)	(C,D,S)
(C,V,N)	(C,E,N)	(C,D,N)

Visually it can be displayed as three-dimensional model of cubes Fig. 6.

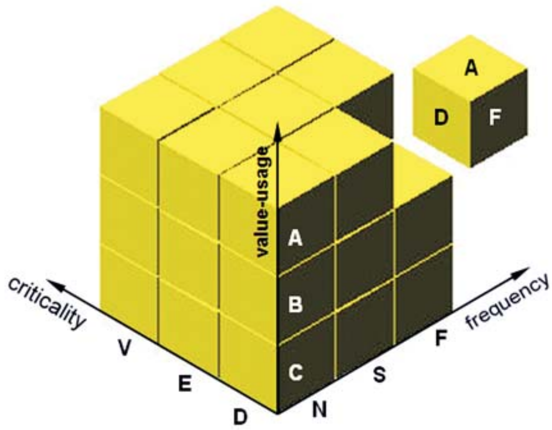

***Figure 6** Possible combinations of parameters*
***Slika 6.** Moguće kombinacije parametara*

Inventory model needed for each item, which means for each of the possible combinations of parameters:

- define management policy
- choose an appropriate method for prediction of demand
- predict the demand of individual items for specific periods
- predict the total demand of all items for the year and the total required funds for this demand.

Data necessary to be known:

- item's name and label
- the inventory numbers of machines, where some spares are used
- label and name of supplier
- lead time for each supplier
- ordering cost
- inventory cost coefficient
- the cost of lack of spare in inventory
- purchase value
- pieces in stock
- tag of the physical places in the warehouse where the spare is
- desired level of service
- dates each spare is taken from the warehouse
- quantity of taking
- quantity in one packaging.

First, it is necessary to clarify the policy management of spare parts and components. There are three basic policies of managing spare parts and components. Those are:

- without keeping spares in stock
- one piece in stock

- more pieces in stock.

a) **Policy management without keeping spares in stock**
This policy includes the purchase of spares just in time of demand. This is the most preferable approach because it employs a minimum of capital and a minimum of space for storage. In order to apply this approach, it is necessary to have reliable suppliers.

The policy can be applied:

- If the cost of stock out is less than the holding cost for the mean time between demand

$$C_{\mathrm{PJ}} \cdot LT < SVRK \cdot h \cdot C \tag{1}$$

where is
C_{PJ} – value penalty
LT – average lead time
$SVRK$ – mean time work to failure
h – cost coefficient of keeping item on stock
C – item unit value.

- To items of high value-usage, if the frequency of demand is not high
- To medium value-usage items, if the frequency of demand is not high and if they are not vital spare,
- To small value-usage items, the frequency of small demand and small criticality.

b) **One piece in stock**
This management policy implies ordering just in time when spare is taken from stock.

This policy can be applied on:

- Critical spares medium frequency of demand,
- Mean value-usage items and medium frequency demand,
- Small value-usage items, mid-frequency demand and low importance,
- Small value-usage items, the frequency of low demand and high and medium criticality.

c) **More pieces in stock**
In all the cases that were not previously mentioned, it is possible to implement this policy. It implies stocking more than one piece of a particular item. Inventory level, safety stock, the type of inventory control, and the order replenishment are determined by the item membership to particular group in decision matrix.

To clarify joining of the management policy to particular items, the three-dimensional model is separated into three two-dimensional decision matrices as shown in Fig. 7.

According to Fig. 7 policy of keeping several pieces in stock joining EOQ model storage (economic order quantity) or one of the dynamic models of storage.

Therefore, it is necessary to analyze the demand in the previous period and to establish whether this is a nearly constant demand or request of occasional character. If it is an occasional character demand, recommendation is to use dynamic order replenishment models (e.g., Wagner-Whitinov or Silver-Meal model), and if it is a nearly constant demand, recommendation is to use EOQ expression:

$$Q = \sqrt{\frac{2D \cdot C_n}{h \cdot C}} \text{ (units)} \tag{2}$$

where is
D – annual demand, units
C_n – fixed costs per order
C – billing price of spare
Q – the number of ordered spares, lot size (units)
h – coefficient of the holding cost.

Group items of great value-usage (Group A)

Frequency	D	E	V
F	One piece in stock	More pieces in stock EOQ or dynam. model Contin. control	More pieces in stock EOQ or dynam. model Contin. control
S	Without stock	One piece in stock	One piece in stock
N	Without stock	Without stock	One piece in stock

Criticality

Group items of medium value-usage (Group B)

Frequency	D	E	V
F	More pieces in stock EOQ or dynam. model Contin. control	More pieces in stock EOQ or dynam. model Contin. control	More pieces in stock EOQ or dynam. model Contin. control
S	One piece in stock	One piece in stock	One piece in stock
N	Without stock	Without stock	One piece in stock

Criticality

Group of small value-usage items (Group C)

Frequency	D	E	V
F	More pieces in stock EOQ or dynam. model Contin. control	More pieces in stock EOQ or dynam. model Contin. control	More pieces in stock EOQ or dynam. model Contin. control
S	One piece in stock	More pieces in stock EOQ or dynam. model Contin. control	More pieces in stock EOQ or dynam. model Contin. control
N	Without stock	One piece in stock	One piece in stock

Criticality

***Figure** 7 Joining of the management policy to particular items*
***Slika** 7. Spajanje politike upravljanja na pojedine stavke*

***Figure 8** Concept dialog for joining of the management policy to particular items*
***Slika 8.** Koncept dijalog za spajanje politike upravljanja na pojedine stavke*

Re-order point can be calculated on the basis of the level of service or according to the method of minimizing the total cost. In cases of EOQ model a periodic review or continuous review model can be selected.

For the policy "without keeping inventories" as well as by keeping only one piece in stock, ordering is done just in time of demand.

The concept dialog for a computer program that solves this issue is shown in Fig. 8.

4 Conclusion
Zaključak

The management of spare parts is very important for every manufacturer.

This article proposes the use of the multicriteria inventory model for optimizing costs related to spare parts. The proposed criteria for optimization are: value-usage, criticality and frequency of demand. Mathematical model for joining management policy to each inventory item would be too complicated for practical use. Therefore a model is proposed based on the classification of spares in similarity groups using classical ABC analysis. Each group is joining adequate management policy. The concept dialog for a computer program is given for easy model implementation in practice. The inventory model is simple and clear for implementation in everyday practice and enough efficiency for inventory cost reduction.

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