Knapsack Problem for Build Spare Parts Stock

Robert Szczyrbak

September 9, 2024

Knapsack problem for build spare parts stock

Robert Szczyrbak[1]

Abstract. The manufacture of products and services involves the operation of machinery and equipment. In the course of operations, machinery gradually wears out, causing product defects, breakdowns or even to accidents. Product defects and failures strongly affect the OEE rate. Machine failures reduce the availability rate. The role of the maintenance department is to ensure the safe and continuous operation of the machinery fleet. For this purpose, the costs of technical materials and labor costs are incurred.

Ensuring continuous operation of the machinery park is both the implementation of periodic inspections associated with the replacement of worn-out components, but also the minimization of repair time. The main factor causing an increase in repair time is the lack of possession of the required parts in the technical warehouse.

In addition to standard indicators related to logistical aspects, it is worth using mathematical models for this purpose, such as integer programming models. To develop such a model, the research problem should be defined. It can be related both to reducing the value of the warehouse or total reduction of fixed costs, but also to raising the value of the machinery availability index. This paper shows knapsack problem, which can be used in technical warehouse. The main goal of this model is to minimize loses in production due failures

Securing in spare parts of the machinery park is a very important part of the management strategy. Decisions related to whether or not to have a particular component are worth justifying with appropriate arguments formed on the basis of analyses of availability and uniqueness of spare parts. It is also worth remembering that parts in stock are subject to obsolescence and in a few years a given component may not fully perform its functions.

Keywords: maintenance, Operational research, spare parts, knapsack problem

1 Introduction

Main goal of maintenance departments is to keep in good condition all machines in factory. They do this by periodically inspecting machines, replacing wear parts and overhauling machines. But there is a risk, when factory has got many production lines. Good practice is to set machine classifitaction. Santos et. al. [7] prepared a practical and structured method of equipment classification criticality based on its importance for the productive process, which culminated in the equipment classification into three categories (A, B and C). This method included five factors: Quality, Availability, Safety and Environment, Costs and Technological Complexity. When we have got machine classification we can set similar classification for spare parts. Before we start, we need to know what spare parts is. Ramaganesh et al. [5] defined spare parts as a interchangeable parts that are retained in inventory and used for failed unit repair or replacement. Spare parts availability has a huge impact on breakdown time. Maintenance teams need to know which parts they should stock to avoid long downtimes that generate high costs. The unavailability of the needed spare parts will affect the efficiency of the machine and incur unnecessary costs. Yet overstocked replacement parts can also incur costs in terms of inventory cost. Two related logistics operations are the provision of spare parts and scheduled repairs, which must be viewed together to achieve cost-effective and reliable logistics support. Afifi et. al. [1] said that to increase machine availability, several components in the machines should be replaced before failure occurs. Therefore, optimizing spare parts inventory management is a key factor in improving maintenance activities. Hu et. al [2] observed that the cost of spare parts takes a large share of product lifecycle cost. Maintenance departments include the delivery time of the required parts in their machine maintenance plans. In order to avoid a capital freezing situation, parts are delivered several days before the work is started. Several activities in maintenance departments can be analyzed and solved by using operational research. This paper shows one of approach to maintenance problem.

[1] AGH Univeristy of Krakow, rszczyrbak@agh.edu.pl

2 Literature review

Spare parts management process affects the performance of maintenance. Availability of spare parts has major impact for stock building. Rinaldi et. al [6] notice that the spare parts refer to service parts, replacement parts, or repair parts that are used to support maintenance and repair operations. The spare parts supply chain differs from the other supply chains for different reasons, mainly the uncertainty and the variability of the demand, combined with the high service level required.

Throughout the last decades we can use useful technique in the field of operations management, several can be used for managing spare parts, mainly for modelling and evaluating inventory policies.

This section is divided into 2 topics: spare parts management approach and knapsack problem in operational research.

2.1 Spare parts management approach

Texeira et.al. [8] said that the spare parts management has obtained great interest in literature. Various topics are addressed concerning spare parts, such as inventory control, demand forecasting and reliability, and supply chain management. This paper focuses on framework of spare parts management according to operational research and classification methods. They also gave advice to set the stock management policy, it will be important to take into account two aspects: the number of machines for which the spare parts are used and the demand for spare parts. There is better situation where we have got more than one type of machine in factory. If we have got very different machines, we need to buy many spare parts.

Hu et. al [2] marks out the questions in spare parts management about decisions which parts are to be stocked as spare parts, when and how many parts should be ordered to bulid or refresh the stock. Spare parts management should refer to life cycle of machine. In their article, life cycle cost (LCC) is closely connected to investment and management of spare parts inventories. In general, the equipment lifecycle process can be divided into three main phases:

- Initial procurement phase
- Normal operation phase
- End-of-life phase

When the LCC is set we can assess spare parts by some criteria. Each phase has got different criterias. They are determined by different needs at the mentioned phases.. In the first stage, we will need parts, qualified as consumable and parts whose criticality is at a high level. The second phase represents the longest life cycle of the machine. so we should take care of repair kits and optimize EOQ and reorder point. In the long run, we should also watch out for emerging component modifications. It happens that manufacturers withdraw the component we use, and we must then carry out an upgrade. If the number of recalled parts is significant and the manufacturer announces the end of support, we should make a decision: secure in the components still available or prepare to replace the machine. In the last phase, depending on our decision, we should focus on the parts we will not use. They represent frozen capital, which will be very difficult to withdraw. The total cost of decommissioning the machine may be increased by the cost of decommissioning the spare parts in inventory.

Texeira et. al [8] suggest one of approach in classification. In first step they define a criticality of spare parts. The main object is to assign to each spare part a level of criticality using the designation VED:

- Vital: Part failure have great impact on production processes,
- Essential: Part failure have middle impact on production processes,
- Desirable: Part failure pose no risk to the production processes.

In second step criticality is combined with spare parts price and lead time. Also they recommend to create the stock management policy two aspects: the number of machines for which the spare parts are used and the demand for spare parts.

Another approach use Mixed-Integer Linear Programming (MILP) with algorithm. Afifi et. al [1] expand their first model called “Periodic Preventive Maintenance’’. They integrate into PPM model the spare parts inventory policy by proposing a new model as ‘‘the Periodic Preventive Maintenance and the Spare Parts Inventory Problem’’ (PPMSPIP). The proposed model synchronizes both decisions:

- periodic maintenance scheduling,
- spare parts inventory management.

Next step they created hybrid memetic algorithm (HMA) for PPMSPIP. They tested their algorithm on 5 machines. Their Hybrid Memetic Algorithm (HMA) and PPMSPIP were coded in C++ and was run sequentially with the MILP solver.

2.2 Knapsack problem in operational research

The Knapsack problem can be use in resource allocation, cargo loading, project selection, investment decision, and other fields. Li et. al [4] said that this is a typical NP-hard combinatorial optimization problem. He et al [3] noticed many extensions of 0-1 knapsack problem. They listed multidimensional knapsack problem, multiple-choice knapsack problem, multiple knapsack problem, quadratic knapsack problem, set-union knapsack problem, max–min knapsack problem, discounted {0-1} knapsack problems, knapsack problem with setup (KPS) and knapsack problem with single continuous variable. Zhou et al. [9] formulated the goal of this problem as to maximize the total value of the items in the knapsack, while constraints ensure that the sum of the weights is less than or equal to the knapsack's capacity.

There are many algorithms which are based on knapsack problem. Li et. al. [4] compare the Binary quantumbehaved particle swarm optimization (BQPSO) algorithm with quantum-behaved particle swarm optimization algorithm (QPSO) and expand for another algorithms.

He et al [3] said that the evolutionary algorithm (EA), such as genetic algorithm (GA), particle swarm optimization (PSO), differential evolution (DE), ant colony optimization (ACO) and group theory based optimization algorithm (GTOA) and so on, are a kind of important metaheuristics, which have the advantages of simple parameters, strong applicability and generality, and easy to implement.

3 Knapsack problem – case study

3.1 Purchasing spare parts problem – case study

Purpose of formulation new version of Knapsack problem is decision of purchase spare parts to avoid high losses due the breakdowns. According to original version of Knapsack problem prepared Purchasing Spare Parts Problem (PSPP) model. In this case machine's supplier sent the offer with 50 items. All of them cost more than 1,2 million EUR. Amount of our budget for this case is 400 thousand EUR.

We have a set of spare parts described by several parameters:

1. Sets:
   a) i – spare part, $i \in S$;
2. Parameters:
   a) c_i – price of spare part *i;*
   b) s_i – losses if we have a spare part *i* during the breakdown;
   c) l_i – losses if we do not have a spare part *i* during the breakdown;
   d) p_i – probability of breakdown spare part *i*;
3. Decision variable
   a) x_i= 1, if we buy spare part *i*, 0 otherwise

Based on the above parameters and set, the binary programming model of problem is given below:

$$\min losses = \sum_{i \in S} s_i * x_i * p_i + l_i * (1 - x_i) * p_i \qquad (1)$$

s.t:

$$\sum_{i \in S} c_i * x_i \leq b \qquad (2)$$

Parameters s_i and l_i include price of item *i*. but rest of their components are different. Parameter s_i describes the value of losses when parts are available in stock. The value of the parameter includes, for example, the cost of spare parts, the cost of storage and the cost of repair. Parameter l_i ignores the cost of warehousing, but can include the value of lost sales and fines. Other costs such as labor of employees or scrap are proportional to lead time of parts. The parameter p_i represents the probability of component failure.

3.2 Results and discussion

The PSPP model was prepared in AMPL and solved by GLPK Integer Optimizer v4.43. The computational experiments were prepared and on a Lenovo IdeaPad computer with an 11th Gen Intel Core i5 processor and 16GB RAM. Model has been successfully generated and processed. Integer optimal solution was found in 0,0 second. During process 0,2 Mb conducted of memory was used.

In optimal solution we can buy 12 items. Amount of objective function is more than 67 thousand EUR. The number of spare parts purchased is determined by the size of the budget. Model does not apply if the total value of the offer will be within the budget.

The main step in this model is to determine what costs will be incurred when the replacement part is in our possession or not. the probability of component failure can be estimated in cooperation with the manufacturer of the machine.

4 Conclusion

According to Li et al. [4] and Zhou et al. [9] knapsack problem can be used to solve any problem. This paper shows using it in spare parts management. Furthermore the PSPP model can be expand by add some new constrains for e.g. exclusion one item by another. We can set parameters according to spare parts classification. Hu et. al [2] noticed that the classification of spare parts permits the identification of the most important spare parts. Then managers can use different inventory strategies for different classes of spare parts, and prioritize the most important items in spare parts management.

Binary decision variable in this problem gives only “yes or no” decision. We do not know how many one part we should buy. This model can be used, when we buy new machine and we decide which parts should be on stock.

Texeira et.al. [8] explained why spare parts management is important for maintain production process. The decision to purchase a spare part should be made at the initial stage of build spare parts stock. Next stages may include models based on economic value of order, reorder points and so on. But there is a risk, when we decide to remove the machine.

According to Hu et. al [2] this paper is about first phase in life cycle machine. As they said in paper when new equipment is introduced, a spare parts replenishment system needs to be established to effectively provide spares supply support.

Maintenance management in any of the approaches whether Time Based Maintenance or Condition Based Maintenance or others includes spare parts management. While we can separate maintenance work into internal and external, we use external sources for spare parts. Proper spare parts management will yield results on the value of assets and the financial result of the company.

References

[1] Afifi Sohaib, Hrouga Mustapha, Mjirda Anis, Allaoui Hamid. *A memetic based algorithm for simultaneous preventive maintenance scheduling and spare-parts inventory management for manufacturing systems*. Applied Soft Computing Journal 151 (2024) 111161

[2] Hu Qiwei, Boylan John E., Chen Huijing, Labib Ashraf. *OR in spare parts management: A review*. European Journal of Operational Research 266 (2018) 395–414

[3] He Yichao, Wang Jinghong, Liu Xuejing, Xizhao Wang, Haibin Ouyang. *Modeling and solving of knapsack problem with setup based on evolutionary algorithm*. Mathematics and Computers in Simulation 219 (2024) 378–403

[4] Li Xiaotong, Fang Wei, Zhu Shuwei. *An improved binary quantum-behaved particle swarm optimization algorithm for knapsack problems*. Information Sciences 648 (2023) 119529

[5] Ramaganesh M., Vikas Varma Ganapathiraju, Rajpradeesh T., Bathrinath S. *Spare parts ordering decisions using age based, block based and condition based replacement policies*. Materials Today: Proceedings 46 (2021) 7854–7859

[6] Rinaldi Marta, Fera Marcello, Macchiarolia Roberto, Bottani Eleonora. *A new procedure for spare parts inventory management in ETO production: a case study*. Procedia Computer Science 217 (2023) 376–385
[7] Santos T, Silva F. J. G., Ramos S. F., Campilho R. D. S. G., Ferreira L. P. *Asset Priority Setting for Maintenance Management in the Food Industry*. Procedia Manufacturing 38 (2019) 1623–1633
[8] Teixeira Catarina, Lopes Isabel, Figueiredo Manuel. *Multi-criteria classification for spare parts management: a case study*. Procedia Manufacturing 11 (2017) 1560 – 1567
[9] Zhou Yongquan, Shi Yan, Wei Yuanfei, Luo Qifang, Tang Zhonghua. *Nature-inspired algorithms for 0-1 knapsack problem: A survey*. Neurocomputing 554 (2023) 126630