**Initial spare parts assortment decision making for rolling stock maintenance: a structured approach**

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**Abstract**

Design for maintenance and maintenance operations become increasingly important in recent years. In the capital-intensive industry, maintenance expenditures can add up to several times the initial investment. In order to be competitive in their business, owners and users of these capital goods have to take into account the total life cycle cost at investment (the lifespan of a train is about 30 years), the renewal decisions for their installations and the logistic management of the spare parts. Erroneous or unstructured initial spare parts assortment decision-making part of the logistic management can lead to undesired downtime and increases the risk of obsolete or unavailable components. Decision making is further complicated by non-existent data in the early design phase and several information management problems. Based on a case study at NedTrain (the largest maintainer of rolling stock in the Netherlands) and literature review a Decision Support Model to structure and to improve the initial spare part assortment for the rolling stock maintenance is proposed.

Keywords: Maintenance Operations, Capital Asset Management, Design for Maintenance, Spare Parts, Support Decision Making
1. Introduction

When a new Train series is introduced at the right moment there has to be made a timely decision on the initially needed spare parts to have NedTrain provide adequate, safe, reliable and comfortable rolling stock at the right place for each passenger’s journey every day.

The initial spare parts decision has not only to be made just but also in time because of the lead times. At NedTrain research shows this lead times can be variable and long and therefore need to be made before construction starts (1,5 year before). However ordering unneeded or wrong spare parts can lead to a significant increase in the spare part holding costs. Therefore not only a good decision making model is needed but also decision process which is adaptable to the available information. Finally because of the importance of information it is necessary to have good information management. Having the right information at the right moment is however complicated by several challenging issues in data management partly caused by an increasing trend in outsourcing [1], e.g. Nederlandse Spoorwegen (NS) stopped to engineer new trains by itself. NS thereby lost the full control over train technology and over the technical documentation.

First of all the present paper will review the existing models and then will explore the problems with applying these models in practise based on a case study at NedTrain. Then principles for the design of a decision support method will be discussed. Finally a decision support method will be proposed to structure initial decision making.

2. Initial spare parts management

There is broad literature on spare part management; they however all assume the initial spare parts assortment as ‘given’. According to Driessen [2] there is no specific literature about the decision whether to add a spare part to the initial assortment or not. However, closer analysis of the literature reveals that some literature sources discuss the (initial) spare parts assortment decision-making process without going much into detail.

Almost all quantitative methods are based on the Recommend Spare Parts List (RSPL), the failure rates λ or on the Mean Time Between Failure (MTBF). These data should be provided by the supplier or is based on operational experience. The most prominent available quality method is the method of Jones [3] which uses Maintenance Task Analysis (MTA) to determine the spare parts assortment. However, for the initial spare parts decision making there is often not enough data available to make a detailed MTA possible and worthwhile in the initial stage. Table 1 lists some of the identified literature and show the relevant keywords and the data used for the assortment decision making.
Table I: Relevant data literature on the most common spare part decision models.

<table>
<thead>
<tr>
<th>Name of the method</th>
<th>Used input data</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEN-EN 13460 (2009)</td>
<td>RSPL, MTBF(^1)</td>
</tr>
<tr>
<td>Driessen et al. (2010)</td>
<td>RSPL, MTBF, operational costs</td>
</tr>
<tr>
<td>Jones et al. (2006)</td>
<td>RSPL, (\lambda), MTA(^2)</td>
</tr>
<tr>
<td>Diallo et al. (2009)</td>
<td>RSPL, (\lambda), FMECA, reliability, availability(^3)</td>
</tr>
<tr>
<td>Aït-Kadi et al. (2003)</td>
<td>RSPL, criteria based on available data</td>
</tr>
<tr>
<td>Smith et. al (2011)</td>
<td>similarity, criticality, MTBF, safety, holding costs, lead team, maintenance costs</td>
</tr>
</tbody>
</table>

Keywords used: documentation, maintenance, assortment management, decision, spare parts management, multi-criteria, spare parts, technical documentation

2.1 Spare parts characteristics

In order to successfully manage spare part inventories the maintenance department needs to know the different characteristics of every single spare part (or at least of every spare part class) to classify parts in the decision-making model and to decide their stocking policy.

As for the decision model, the literature provides an extensive list of common procedure for classifying spare parts; some of these procedures are now very briefly explained in order to make easier the comprehension of the next part of the research work.

2.1.1 Spare parts characteristics decision techniques

The following classification can be used as a starting point in the initial spare parts assortment decision making.

Table II Relevant decision technique based on spare parts characteristics.

<table>
<thead>
<tr>
<th>Name</th>
<th>Keywords</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSN</td>
<td>Fast, Slow, Non-moving</td>
<td>Technique based on the usage rate of the spare parts; determining fast-moving parts help in deciding which parts need to be stocked close to the asset</td>
</tr>
<tr>
<td>SDE</td>
<td>Scarce, Difficult and Easy to procure</td>
<td>Technique based on procurement lead time. Scarce items are generally imported and require more than six months lead time</td>
</tr>
<tr>
<td>VED</td>
<td>Vital, Essential and Desirable</td>
<td>Technique based on the criticality of assortment. A vital part not available has a major effect on the production downtime</td>
</tr>
<tr>
<td>ABC</td>
<td>Always Better Control</td>
<td>Technique based on annual consumption value calculated with the Pareto analysis</td>
</tr>
</tbody>
</table>

\(^1\) RSPL (Recommended Spare Parts List), MTBF (Mean Time Between Failure)

\(^2\) \(\lambda\) (failure rate), MTA (Maintenance Task Analysis)

\(^3\) FMECA (Failure Mode, Effect and Criticality Analysis)
assigning all the spare parts to three categories

| HML | High, Medium, Low unit price | Technique based on sorting the spare parts according to their unit price |

As suggested by Huiskonen [4], forecasting and planning the demand, the procurement lead time, the criticality, the annual usage value and the unit price of the parts for complex capital assets like trains, could produce an unmanageable amount of classes. Therefore a choice on a combination of categories has to be made.

If more than two criteria are needed, multi-attribute classification models could be used Braglia [5] and Gajpal [6] assigning with an Analytic Hierarchy Process (AHP) relative priorities or weights to different criteria.

Driessen continues by stating that few spare parts decision model take into account a multi-criteria classification, the presence of ‘partial information available’ and the event of ‘no data available’.

As a consequence, an important challenge for initial spare parts assortment decision making is gathering the proper information and the technical documentation to identify the most essential spare parts.

### 2.1.2 Gathering technical documentation

Gathering technical information and documentation is vital to set up a correct spare parts management policy.

In terms of resources saving, it could be preferable to spend time on collecting and maintaining technical information (criticality, redundancy, commonality, specificity, substitution, life span, position in the configuration and reparation) from the suppliers for spare parts relatively expensive, not easily available and important for controlling supplying risk and operational costs, than gathering technical information for relatively cheap and easily available parts.

Smit [7] presents a possible description of the documentation typology for spare parts. In Figure 1 these characteristics are shown with the cross-references between the documentation.

![Figure 1. Documentation typology for spare parts](image)

Unfortunately, in practice it is not always possible to gather all presented information.
Suppliers are not always willing due to confidential data and marketing strategy related issues with their customers or able to timely share the information.

2.2 The case study: the introduction of the Sprinter Light Train (SLT)

In our research we will use the introduction of the Sprinter SLT to research the specific context in which initial spare parts decisions are made.

The Sprinter Light Train (SLT) series, Figure 2, was introduced in 2009 to replace the outdated Mat ’64 train series. The SLTs are electrically driven train built by the Bombardier-Siemens consortium. NedTrain needs to maintain 131 SLT's: 69 four-carriage (SLT-IV) and 62 six-carriage (SLT-VI) trains for over 30 years. Therefore, a spare parts assortment decision-making process had to be identified.

![Figure 2. Two SLT at NedTrain's workshop in Leidschendam, The Netherlands](image)

2.2.1 The Sprinter Light Train assortment

The first two years after the introduction (start of transporting passengers), the supplier is responsible for spare parts management according to the warranty agreement. This means that the supplier has to deal with parts that fail unexpectedly (infant mortality failure rate).

The Bombardier-Siemens Consortium positioned their engineers and placed their own spare parts in Leidschendam. Whenever a part had to be replaced or repaired because of warranty, the consortium engineers solved the problem.

But, after the warranty period NedTrain takes over this responsibility with the possibility to obtain the spare parts that the Consortium has still on stock.

At NedTrain, the maintenance-engineering department is responsible for the initial spare parts assortment decision making. Staff of this department decides on the assortment with the use of information obtained from suppliers and from own experience. After the initial spare parts assortment is determined, the procurement and logistics staff will decide to purchase parts or not and the amount of spare parts.
NedTrain has several different levels in their repair network. There are called service companies, maintenance companies, a refurbishment and overhaul workshop and a components workshop.

Because of NedTrain has to maintain trains for over 30 years, the spare parts assortment is significantly different from the first two years compared with the assortment decision made by the supplier.

Manufacturer delivered spare parts recommendations failure rates, unit price; minimal order quantity, yearly usage for preventive maintenance information are all potentially available for making the decision.

The available information was reviewed by the maintenance engineer (ME) adding information, based on the experience, such as yearly corrective maintenance usage, part classification warranty status, common train series parts and external factors (water, snow and ice effects, vandalism acts…).

The initial assortment held about 1600 parts; after few months the assortment was updated to about 2100 parts according to new technical information gathered (part drawings, maintenance manuals and information on form, fit and function).

2.2.2 The problem and the uncertainties during the Sprinter Light Train assortment decision-making process

The problems and uncertainties in the spare parts assortment decision-making process of the SLT that arose during the interviews were mainly related to the technical information and to the poor communication between the different stakeholders involved in the process:

1. Communication problems (if NedTrain wants to have more information from the suppliers, the consortium had to be contacted to send the request of information to the suppliers, Figure 3) due the outsourcing of the engineering design, this takes considerable lead-time and not always the ‘right’ quality of information is provided;

2. Data hand-over problems (gathering all the documentation in a detailed level is expensive causing additional work for the consortium and for the suppliers)

3. Information is not easily provided by suppliers because with this information NedTrain can eventually contact suppliers directly to buy parts for lower costs. For the initial assortment NedTrain is however strictly bind to the consortium due to the terms of the contract;

4. Content uncertainty on the obtained information (the safety margins the consortium adds to the safety margins of suppliers cause inaccurate data. Lead times are too long, and parts become more costly than necessary);

5. Future availability uncertainty (the possibility for spare parts included in the assortment to be never used during the lifecycle span of the train) but have to be purchased because there is sometimes only a single option to buy them;
It means that at the beginning of the use phase, the uncertainty on spare parts availability is considerably low; but, according to the lifespan of the train, the uncertainty on future spare parts availability will arise after the first using phase.

3. Design of a decision support model: SAISAD (Structured Approach for Initial Spare parts Assortment Decision-making)

As discussed in the previous paragraph, the spare parts assortment after a couple years of the train live might change a lot than the initial assortment: parts have to be added to the assortment during the using phase due to unexpected failure or difference in the Line Replaceable Unit (LRU) / Shop Replaceable Unit (SRU) level. To be able to set up a more suitable assortment, a Decision Support Model which combines some spare parts criteria together with a decision making approach is created. The suggested approach was inspired by the method proposed by Aït-Kadi [8].

The SAISAD method, is composed by a logic decision tree approach to create a spare parts assortment, by an evaluation part to consider the Long Term Availability (LTA) and by a special part to take into account the different phase of the process.

3.1 Design criteria for improved structured decision making process

To prevent the spare parts assortment decision making being a “static“ process, the model should be robust and dynamic to fit in every situation; it should support the initial spare parts assortment decision making when a relative great uncertainty in the decision phase is present. Moreover, the model has to prevent issues caused by not including parts in the assortment, considered as the reverse burden of proof.
3.2 SAISAD Part 1: Logic tree and practical principle

To reduce the number of parts to be analysed in the SAISAD model, a logic tree is used as first filter. To make the filter robust and reliable as much as possible the Pareto principle is applied. The Pareto principle states that in a group a significant 20% of the items contribute to 80% of the total problems and vice versa. Therefore in this case the logic tree should reduce the set of parts to be analysed with about 80%. The logic tree is based on four decision points (Figure 5):

- parts that are not sufficiently similar to already known parts;
- parts that are not decisively influenced by external factors;
- parts that are significant and have a price higher than 250 €;
- parts that are not significant and have a price higher than 10,000 €;

![Diagram](image.png)

Figure 5. Part 1: Logic Tree Approach of the SAISAD model
3.3 SAISAD Part 2: Evaluation Part for the Long Term Availability (LTA)

The evaluation part helps the decision maker to simplify a large complex decision problem into several smaller problems [9], combining Long Term Availability (LTA) of the spare parts identified during the logic tree phase with criticality categories. The criticality of the part is extracted from the available FMECA documentation related to the part.

![Figure 6. Part 2: Long Term Availability (LTA) combined with Vital criticality of spare parts](image)

The output of the evaluation part is an Importance Factor (1 important - 3 least important).

In Figure 6, a Vital criticality and a Vital LTA final importance factor is calculated. The Vital criticality always gives an importance factor 1. When a part is critical, the LTA does not matter: the importance will be high. For parts which have an Essential criticality the LTA does matter; a Vital LTA will yield an importance factor 1. Similarly, Essential and Desirable LTA’s will yield an importance factor 2.

When the criticality is categorized as Desirable, the LTA can give importance factor 2 (for Vital and Essential LTA) or 3 (Desirable LTA).

For each of the important decision, policies are created and assessed in the third part of the SAISAD model.

3.4 SAISAD Part 3: Spare parts assortment decision making

The improved spare parts assortment decision making is formed by an evaluation moment and an expert session.

3.4.1. Evaluation moment

The evaluation moment is created to gather the last information to manage the uncertainty in the initial spare parts assortment decision making. In Figure 7 the advised policy at the first evaluation moment is shown.

Parts with importance factor 1 are added to the assortment to be ordered. Parts with importance factor 2 are not added to the assortment at this moment due to the level of uncertainty; the available data is inconclusive on the assortment decision making.
Those parts have to be evaluated in an expert session to investigate to require extra information from the supplier and which information has to be requested. Parts with the lowest importance factor (3) are not added to the assortment; no data is gathered because these parts have a low criticality and LTA.

![Figure 7. Evaluation Moment](image)

3.4.2. Expert Session
To decide on the parts with importance factor 2 the expert session will take place. The maintenance organization needs to have the right technical documentation available reducing and preventing future spare parts unavailability. The people involved in the initial spare parts assortment decision-making process are maintenance engineers and spare parts assortment experts.

As discussed in the paragraph 2.1 and according to Watts [10], there are several groups of technical documentation could be helpful during an assortment decision making.

Due to the complexity of the asset to maintain, the expert session have to take into account different aspects to reduce the uncertainty on the spare parts assortment.

The table below underlined the documents required during the expert session.

### Table III Technical documentation taken into account during the expert session for the spare parts with Importance Factor 2.

<table>
<thead>
<tr>
<th>Technical documentation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales Document</td>
<td>Mostly logistic information about the parts. Lead time, minimum order quantity, storage conditions etc.</td>
</tr>
<tr>
<td>Design documents</td>
<td>Design documents define the product or critical process elements. These documents include part drawings, product specifications, parts lists, material specifications, etc.</td>
</tr>
<tr>
<td>Support documents</td>
<td>Support documents define the information necessary to install, use or maintain the product. These documents are the product description manual, maintenance manual and installation instructions.</td>
</tr>
<tr>
<td>Manufacturing documents</td>
<td>Manufacturing documents define the manufacturing process. The tool/fixture drawings, inspection process documents and routing/process sheets. These documents give the needed information to either re-manufacture the parts or to choose external producers to manufacture them.</td>
</tr>
</tbody>
</table>
Conclusion and further research

To design a structured Decision Support Model for a rolling stock maintenance organization is vital to improve the initial spare part assortment in the pre-operational phases in order to maintain a complex capital asset formed by 25,000 parts. The SAISAD model improves the control on the initial spare parts assortment decision-making process, reducing the number of parts with a decision tree approach and classifying them according to their criticality and to the Long Term Availability (LTA).

The Long Term Availability is a quantitative estimation of the future availability of the parts and of the supplier affected by an uncertainty. For these reasons, the knowledge of the maintenance experts represents a not negligible value and it is required during the expert session.

The maintenance organization should therefore find ways to decrease the future uncertainty of the spare parts; it represents the next action.

To increase the maintainability of the assets and, on the other hand, to ensure a more dynamic spare parts assortment and a long-term availability contracts with suppliers, NedTrain is planning a new approach called “Next Generation Trains” for the introduction of a new train series on the Netherlands railway.

Based on sharing knowledge during the planning phase, the aim is to realize as much as possible a real designed for maintenance asset that could fitted together with the desires and requirements of all the different stakeholders involved in the purchase process, guaranteeing in the end to have a reliable spare parts assortment during all the live span.

Acknowledgements

The presented paper was inspired by the graduation assignment of Joost Ziggers in Mechanical Engineering at the University of Twente supervised by Dr. Jorge Parada Puig and carried out in collaboration with NedTrain, responsible for the maintenance of rolling stock in the Netherlands.

References


