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The design of a Logistic Support System

How to reduce Life Cycle Costs with 54%?

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Table of contents

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1 INTRODUCTION

Cancelled flights, delayed trains or a fall out of electricity or internet are all events that are very unpleasant, costly and in the meanwhile inevitable. To prevent failure of capital goods such as aircrafts, trains, turbines and servers preventive maintenance is used. In the case that a capital good fails, corrective maintenance is used to repair the capital good as fast as possible. For both preventive maintenance and corrective maintenance a logistic support system is required. A logistic support system is responsible for the supply of spare parts and resources that are needed to repair a failed capital good. Taking into account that capital goods typically have a dispersed installed base and require a high availability it becomes clear that an efficient logistic support system is of utmost importance.

This white-paper addresses the question how to (re)design a logistic support system. More specifically the following topics are discussed:

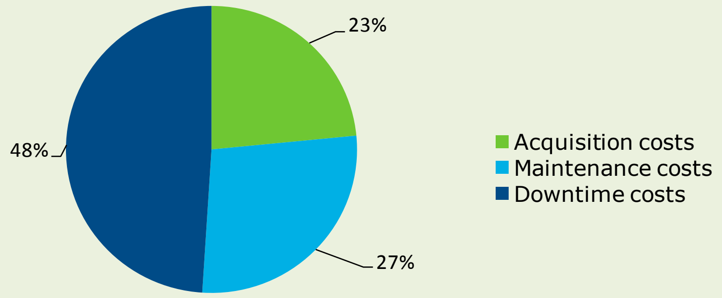
- Which components to replace upon failure?
- Replace a component or acquire a new one (repairable/consumable)?
- Where to repair a failed component (local versus central repair)?
- Where to install resources?
- Where and how many spare parts to stock?
- How many spare systems to install?

1.1 Life Cycle Costs

An emerging trend in (service) supply chains is to apply a Total Cost of Ownership perspective. Using such a perspective is logical especially when looking to the distribution of costs during the life cycle of capital goods. Capital goods in general are expensive, however the initial investment in a capital good typically represents only one-third of all cost incurred during the life cycle.

The costs associated with the maintenance and downtime of capital goods during the exploitation phase account for approximately two-third of the Life Cycle Costs[1] (LCC), as can be seen in Figure 1.

Figure 1: Life Cycle Cost breakdown



Source: Öner et al., "Life cycle costs measurement of complex systems manufactured by an engineer-to-order company" (2007)

Downtime costs for example, are made when a flight is delayed or cancelled due to a technical failure of an airplane. As a result of the delay or cancelation, customers have to be compensated with food- and hotel vouchers, and the crew has to be rescheduled. Maintenance costs are made both preventively and correctively, by for example replacing certain components. The acquisition costs represent the investment and implementation costs when acquiring the systems.

1.2 Logistic support system

The objective of a service supply chain for capital goods is to deliver availability, capability, and reliability. In this white-paper a methodology will be presented that can be used to design a logistic support system such that a certain availability is met, while minimizing both OPEX and CAPEX. Furthermore, managerial insights are discussed that are derived from two business cases that were conducted at a Maintenance Repair and Overhaul (MRO) company responsible for a fleet of trains.

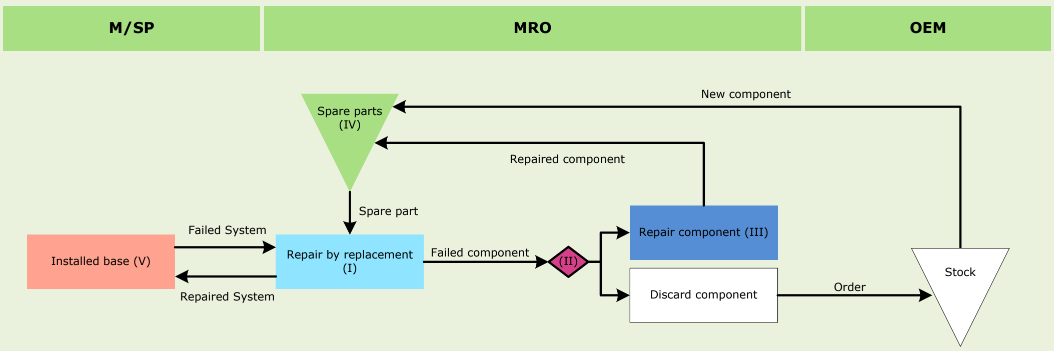
[1] Excluding the potential disposal costs

2 STRATEGIC DECISIONS WHEN (RE)DESIGNING A LOGISTIC SUPPORT SYSTEM

A logistic support system is required to keep the installed base available. When a system of the installed base fails, the logistic support systems is responsible for the repair of the system. Because of high-downtime costs for capital goods, in general the repair is done by replacing the failed component from the system by a spare part. As a result the system is operational within a short period of time. Thereafter, the failed component is either repaired or discarded. In Figure 2 a workflow of a typical logistic support system is depicted. In the workflow three entities are present:

1. the Manufacturer/Service Provider (M/SP) that owns the installed base;
2. the MRO that maintains the installed base;
3. the Original Equipment Manufacturer (OEM) that supplies systems and components.

Figure 2: Trade-offs in a logistic support system



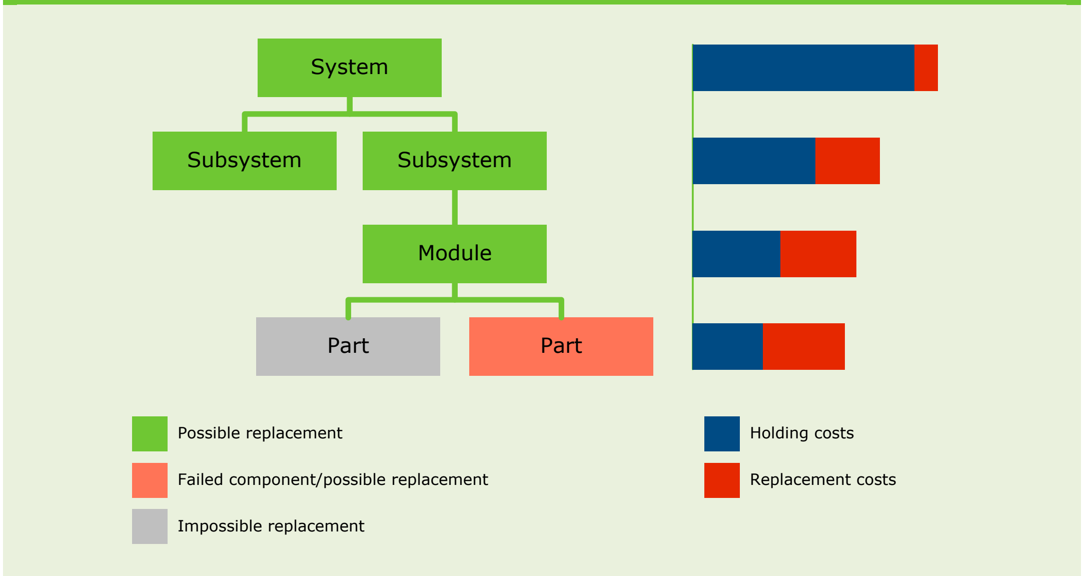
Decision	Description	OPEX & CAPEX	DMU	Level
I	Which component to replace?	Replacement- and holding costs	MRO	Strategic
II	Repair or discard a failed component?	Repair-, aqcuisition- and holding costs	MRO	Strategic
III	Repair local or central?	Resource-, transport- and holding costs	MRO	Strategic
IV	Where and how many spare parts to stock?	Holding costs	MRO	Strategic/Tactical
V	How many systems to install?	System- and spare part costs	MRO&M/SP	Strategic

When (re)designing a logistic support systems several strategic and tactical decisions need to be made. In this white-paper five strategic/tactical decisions are discussed. First in Section 2.1 the decision which components to replace when a system fails is discussed. Then, in Section 2.2 the decision whether to repair or discard a failed component is discussed. When the decision is taken to repair a component, a decision needs to be made where to repair it as discussed in Section 2.3. Given the decision whether and where to repair, the decision where and how many spare parts to stock can be made. In Section 2.4 we discuss the decision where and how many spare parts to stock. Finally, in Section 2.5 we discuss the trade-off how many spare systems to install.

2.1 Which component to replace

When a systems fails the first trade-off is which component to replace. Obviously, one wants to replace the component which caused the breakdown of the system. However, a degree of freedom exists whether to replace the failed component itself or to replace the module containing the failed component. It could be that replacing a module takes less time than replacing a component. However, putting the complete module on stock is more expensive than putting a relatively small component on stock. In Figure 3 the trade-off to either replace a system, sub-system, module or part is schematically depicted.

Figure 3: Indenture structure and costs distribution



2.2 Repair or discard a failed component

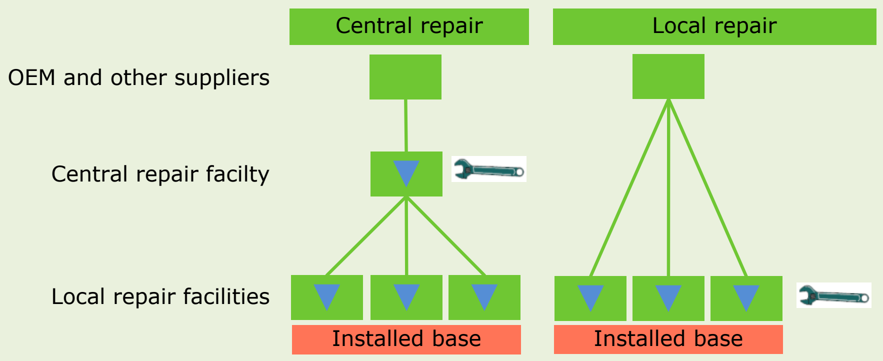
After replacing a component (or module) from the system, this component could either be repaired or discarded. When discarding a component a new component should be acquired. The repair-discard decision depends on the repair costs such as labor- and tool costs. When the repair costs are lower compared to the acquisition costs, obviously the option to repair the component is preferred. However, the lead time associated with repairing or acquiring component also influences the decision whether to repair or discard a component. A higher lead time means that more components need to be stocked and thus more holding costs are occurred. As a result, in some cases it is beneficial to repair components while acquiring them is less expensive (or vice versa).

2.3 Repair local or central

When choosing the option to repair a component, there is the possibility to repair it locally or to repair it at a central location. In Figure 4 a central and local repair network is shown. The advantage of repairing it locally is that the lead time is shorter than when repairing it at a central location.

Furthermore, when repairing centrally a transport is required to deliver the failed good to the central facility and back to the local facility. Nevertheless, often the decision is made to repair components centrally because of the expensive resources that are needed to perform a repair. When repairing centrally less resources are needed compared to a local setup.

Figure 4: Central and local repair network



2.4 Where and how many spare parts to stock

In general a certain target availability of the installed base is stated in the Service Level Agreements. Given this availability, the question is which components to stock, where and how many. The challenge is to keep the holding costs as low as possible. Therefore, the costs of a spare part is important when deciding how many components to stock. When for example two components need to be replaced with the same frequency, but differ in price, it will be beneficial to put more components of the cheapest one on stock.

2.5 How many systems to install

Directly related to how many spare parts to put on stock is the decision how many spare systems to acquire. Spare systems are standby systems that become operational when an operational system fails. An important factor in the number of spare systems is the required reliability of the availability. Furthermore, the acquisition costs of spare parts play a role in the optimal number of spare parts. When a spare part is relatively expensive compared to the whole system, it is likely that acquiring relatively few spare parts but relatively many spare systems is optimal.

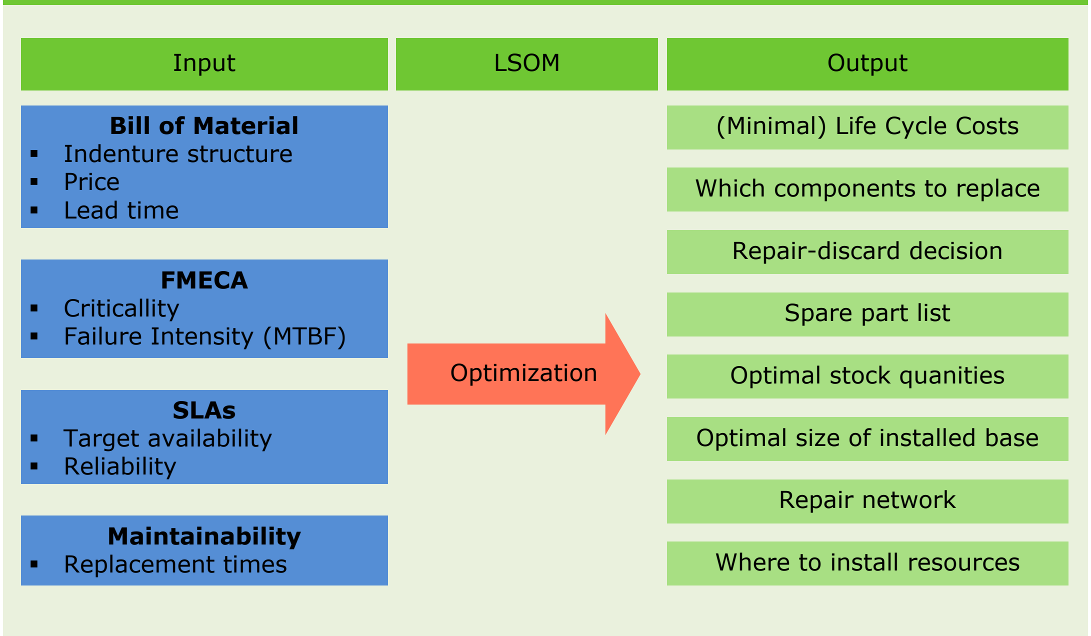
3 LOGISTIC SUPPORT OPTIMIZATION MODEL

Because of the many trade-offs, designing a logistic support system is complex. Furthermore the trade-offs are interrelated and thus optimizing trade-off by trade-off could mean that in the end suboptimal strategic decisions are made. When taking into account that in general the Life Cycle Costs (LCC) of a capital good are in the order millions of Euros, an inefficient solution could result in millions of Euros additional cost annually.

3.1 Input and output

In order to find the most efficient design while taking all trade-offs into account, a Logistic Support Optimization Model (LSOM) is developed. The LSOM is an application that takes into account all trade-offs and integrally optimizes the logistic support system. In Figure 5 the input and output of the LSOM are stated. By inserting data such as a Bill of Material (also called indenture structure), Failure Mode Effect and Criticality Analysis (FMECA), Service Level Agreements (SLAs) and maintainability documentations into the LSOM an optimal logistic support system is quickly achieved. The LSOM is also able to take into account restrictions as a consequence of for example legislations.

Figure 5: Input-Output Logistic Support Optimization Model



3.2 The software

The LSOM is a combination of a Mixed Integer Program and a stochastic program. By connecting the LSOM to a database containing the required input, it is able to solve large instances (i.e. at fleet level).

4 BUSINESS CASES

Two business cases are performed where the LSOM is used to design an optimal logistic support system. The business cases were both performed at a MRO maintaining a fleet of trains. Both business cases concern new train series, therefore no historical data existed. However, the system integrators could deliver sufficient data such that the LSOM could solve the business cases. The data from the system integrator mostly originates from OEMs that already produce and sell the particular system or a similar one. Hence, although the system in itself is new to the market still the system integrator is able to predict the failure behavior.

4.1 Characterization of business cases

Both the high-speed- and commuter train exist of about 1,500 maintenance significant items (i.e. parts that can fail). These parts are divided over 4 relevant indenture levels, meaning that a train consists of sub-systems, modules, components and parts.

The repair network for the high-speed- and commuter train differ. Since the commuter train covers a larger geographical area also its repair network is larger. Hence, the commuter train has a repair network of 4 echelons, whereas the high-speed train has a network of 3 echelons. The target availability for the high-speed train is 16 trains and for the commuter train at least 121trains should be available. A high-speed train costs about €20 million and a commuter train about €8 million per train. The characterization of the business cases is summarized in Table 1.

Table 1: Business cases

Attribute	High-speed	Commuter
Maintenance significant items	1,500	1,500
Indenture levels	4	4
Echelon levels	3	4
Target Availability	≥ 16 trains	≥ 121 trains
Acquisition price	± € 20 mio.	± € 8 mio.

4.2 Results

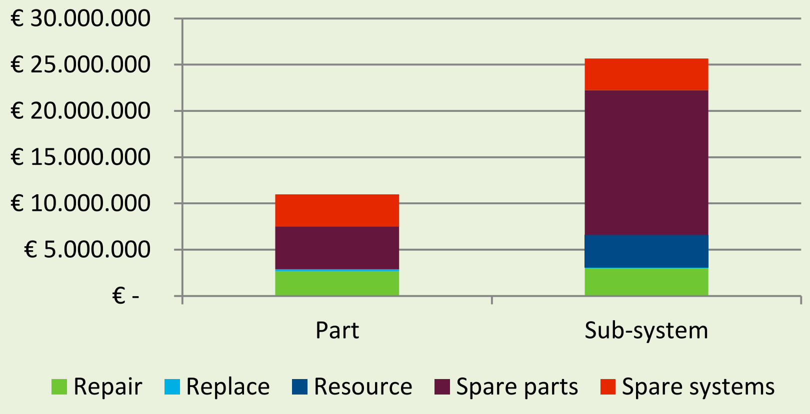
Using the LSOM an optimal logistic support system for the two business cases is designed. The LSOM is used to determine what the optimal logistic support system would be when sub-systems would be replaced upon failure of the system because this is the current practice at the OEM. Furthermore, the LSOM was used to also optimize which components to replace upon failure.

4.2.1 Replacing small parts instead of sub-systems reduces costs with 54%

The use of the LSOM in determining which parts to replace resulted in a decrease of costs with 54% compared to replacing sub-systems. The optimal solution found by the LSOM is to replace parts. In Figure 6 the LCC for an optimal logistic support system when replacing sub-systems and when replacing parts are shown in a graph.

- The higher LCC cost when replacing sub-systems are mainly caused by the higher holding costs. Obviously more holding costs are associated with stocking large expensive sub-systems than when stocking small components.
- The only drawback when replacing small part compared to sub-systems is that more time is needed to isolate the failure. As a result the replacement costs are slightly higher when the strategy is to replace smaller parts.
- Remark that there are almost no resource cost when replacing parts, while there are resource costs when replacing on sub-system level. The main reason for having resource costs when replacing on sub-system level is the need for tools when replacing large parts (heavy) parts.

Figure 6: Annual, replacing part versus sub-system



4.2.2 Discard about one-third of the parts

The optimal design of the logistic support system for both business cases furthermore show that it is best to discard about one-third and to repair two-third of the failed components. By discarding components some resources are not needed that would have been needed when repairing the component. Furthermore, the lead time of acquiring new parts sometimes is shorter than repairing the component (this is especially the case when repairing central). As a result of the shorter lead time, less spare parts are needed. Sensitivity analysis showed that when transport costs are doubled, the number of components that are discarded is increased with 19%. Typically a MRO determines the decision to repair or discard based on the labor, material and acquisition costs. The outcome of the business case proves that is worthwhile to take into account the repair lead time, acquisition lead time, holding costs and transport costs as well.

4.2.3 Central repair is optimal when capital intensive resources are required

The repair of parts for both business cases required capital intensive resources such as tools and knowledge. A local setup means that multiple facilities need to be build and resources need to be installed at the various local locations. The advantage of repairing locally is that lead times are shorter. Repairing centrally requires a transport from local facilities to a central facility and back to the local facility when the repair is performed. Hence, transport costs are occurred when repairing centrally and furthermore the lead time is longer. The business cases show that despite of the longer lead time and transport costs a central repair strategy results in 32% lower life cycle cost compared to a local setup.

Repairing centrally does not mean that systems are transported to the central repair facility. Instead only the failed part from the systems is transported to the central repair facility since a repair by replacement strategy is used. A repair by replacement strategy means that whenever a system fails the failed component is isolated and disassembled and replaced with a spare part. Hence, only the failed part has to be repaired at a central repair facility. In Figure 7 an overview of the replace and repair network is depicted.

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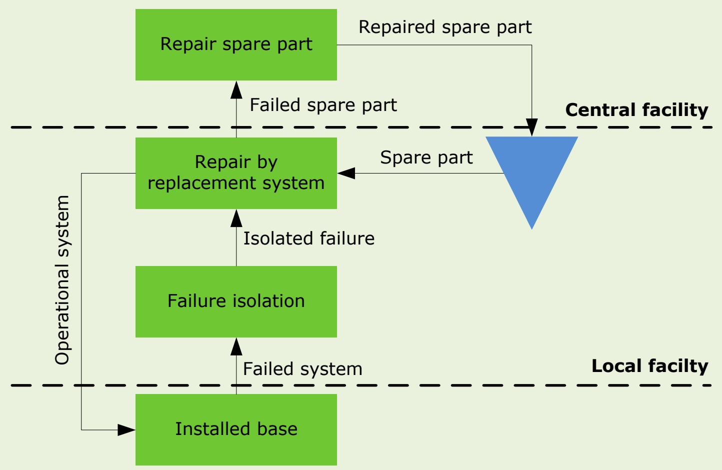
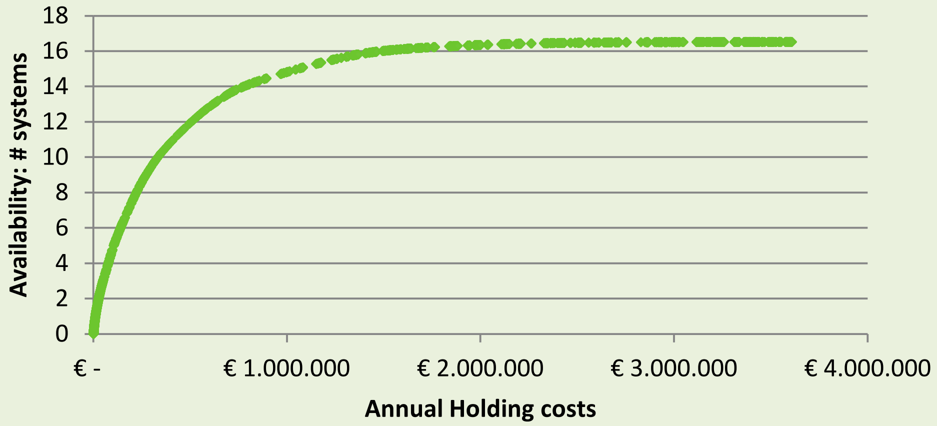
Figure 7: Replace and repair network strategy



4.2.4 Using a system approach could save MRO significant amount of holding costs

The current practice on spare parts optimization in most cases is that an item approach is used to determine the number of spare parts. As a result the costs of a spare part are not explicitly taken into account. The system approach that is used by the LSOM in addition to the item approach does take into account the costs of a spare part. As a result cheaper components are relatively stocked more than expensive components. Furthermore, the LSOM is able to generate an availability curve such as in Figure 8. Since the decision how many spare parts to stock and how many systems to install is related to each other the holding costs for the spare parts only, do not reflect how efficient the solution of the LSOM was. Therefore, in the next section the total cost for spare parts and systems are discussed.

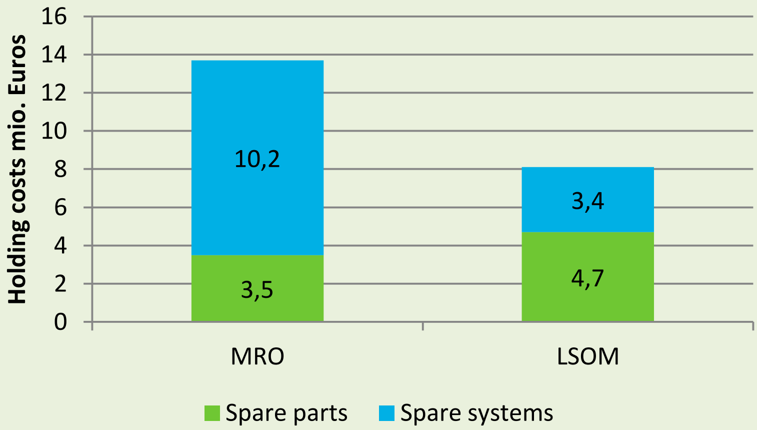
Figure 8: System availability versus holding costs



4.2.5 Optimal trade-off on spare parts and spare system can save 41% of holding costs

The decision on how many spare parts to stock is directly related to the decision how many systems to install. Obviously at least the number of systems that need to be available should be installed. In addition spare systems can be used to compensate for an operational system that fails. By installing more spare systems less spare parts are required. Compared to the solution that the MRO obtained for the high-speed train, the solution of the LSOM was such that less spare systems where installed, to compensate more spare parts are put on stock. The total holding costs obtained by the MRO are 13.7 million Euros whereas the total costs obtained by the LSOM is 8.1 million Euros. Hence, the total holding costs of the LSOM are 41% lower than from the MRO. In Figure 9 the holding costs for the solution found by the MRO and the LSOM are depicted.

Figure 9: Total holding costs, MRO versus LSOM



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4.3 Conclusions

In summary the three most important management insights are:

1. **Replace the smallest isolatable component**
   Typically the focus when determining which components to replace upon failure of a system is based on the replacement time solely. From the business cases becomes clear that this paradigm is far from optimal (i.e. 54% higher costs). When taking into account the holding costs together with the replacement time. It shows that typically the smallest isolatable component should be replaced upon failure of a system. As a result the holding costs can be reduced significantly. Furthermore it could be that no tools are required when replacing small components, where in the case that large modules are replaced often such tools are required.

2. **Replace local, repair central**
   The optimal repair network strategy is to repair by replacement the system local and to ship the failed spare part to a central repair facility. At the central repair facility the spare part is repaired and subsequently is shipped back to the local facility where the spare parts are stocked. The increase in holding costs when repairing central instead of local is only minor compared to the decrease in investment in resources. Thus when having a dispersed installed base that requires expensive resources to be repaired, it is beneficial to repair centrally.

3. **Less spare systems and a little more spare parts**
   The business case showed that it is worthwhile to determine how many spare systems to install and how many spare parts to stock at once. By solving the spare system and spare parts problem integrally, the LSOM derived 41% lower holding costs than the found solution by the MRO.

5 ROAD MAP

Based upon the experience gained during the business cases four important steps that are required to design an optimal design of a logistic support system are:

1. **Gather data, or buy it from the system integrator**
   When acquiring a capital good in most cases it is possible to either receive or buy data from the system integrator. Especially when there is no historical information on the failure behavior of the capital good, it is worthwhile to acquire this data from the system integrator.

2. **Use a relational-database to store the data**
   A capital good exists of many components. For each component data on the relation to other components, price information, repair times, replacement times, criticality and failure intensity needs to be stored and collected. This data originates from different sources such as the logistics, maintenance and finance departments. Hence, it is well advised to couple all this data using a relational-database with a component-ID as an unique key.

3. **Use the Logistic Support Optimization Model**
   When data is stored in a relational-database, it literary does costs less than an hour to find an optimal design for the logistic support system. Since many trade-offs in the design of a logistic support system are interrelated, the use of a spreadsheet will not result in very efficient solutions.

4. **Perform multiple scenario and what-if scenarios**
   Since, it only takes little time to solve a single instance, it is possible to perform scenario and what-if analysis using the LSOM. As a result of these scenario and what-if analysis, the robustness of the optimal logistic support system can be determined. In the case that the optimal design is found to be not very robust, designs that are found in the scenario and what-if analysis can be used instead.

6 ABOUT THE AUTHOR AND GROENEWOUT

Rik Kusters is a Consultant at Groenewout since 2011. Before joining Groenewout, Rik worked as a consultant with a focus on data-analysis, simulation and optimization within the field of supply chains management and logistics. Rik holds a Master's Degree in Industrial Engineering (cum-laude) from the University of Technology in Eindhoven. His specializations are: supply chain management, service logistics, inventory management, warehousing and transport.

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