# The Development and Application of a Value-Driven Aircraft Maintenance Operations Performance Assessment Model combined with Real Options Analysis

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This research paper presents the results from the development of an Aircraft Maintenance Operations Performance Assessment Model (AMOPAM). The AMOPAM is able to assess the differences in performance in between two different states or scenarios of aircraft maintenance operations and is able to capture these differences both in the form of differential-  $(\Delta V)$  and financial value (NPV). The AMOPAM is based on the combination of the Value Operations Methodology and Real Options Analysis. The input variables are Key Performance Indicators that have been identified as value drivers that can capture the operational and financial performance of aircraft maintenance procedures. The model is validated at a real life case at the aircraft maintenance department from KLM (Royal Dutch Airlines) E&M (Engineering and Maintenance). Hereby it was used to evaluate improvement opportunities for its recovery processes used in case of material unavailability. A regression analysis of the results of the case study has indicated a relationship between NPV and differential value. This has offered new insight in how the performance of aircraft maintenance operations can be assessed and how value can be interpreted from an operational and financial perspective.

Keywords: Aircraft Maintenance, Operations Performance Assessment Methodologies (OPAM), Value Operations Methodology (VOM), Real Options Analysis (ROA)

# **I. Introduction**

A ircraft maintenance is known as one of the most complex maintenance operations due to the changing demand caused by the inspections uncovering different types of material needs and repairs along with a varying time to perform them (Mcauliffe, 2007). The market used to be consolidated and the major players where North-American and European MRO-providers. Due to the high local labor costs a shift towards the emerging South-American and Asian MRO-providers has been visible, nowadays offering similar quality levels at much lower labor costs. Seeliger et al. (2006) expects between 2004 and 2014, an increase in MRO revenue by 88% in Latin

America and a 61% in Asia while North America is expected to only see 5% growth. The challenge for all concerned will be to reduce costs while maintaining or even improving quality and reliability. Given the importance of fleet safety, it is imperative to balance cost leadership and value-capture from the maintenance function with quality and reliability (Seeliger et al., 2006).

Due to this constant focus on improving operations in terms of financial and operational value, it is of importance to know the main value metrics that are able to indicate the performance of aircraft maintenance processes. The current literature does not describe general Key Performance Indicators (KPI's) used in aircraft maintenance operations.

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Furthermore, there are currently no Operations Performance Assessment Methodologies (OPAM) for aircraft maintenance procedures described in the literature. In the current challenging MRO-environment it would be valuable to have general KPI's that can capture the operational and financial value and a model in which those can be implemented indicating if value, seen from both perspectives is created or destructed.

Therefore, the following research question has been synthesized:

How can a model assess the operational and financial performance of aircraft maintenance operations based on their value creating abilities?

The outline of this paper is as follows; the second section will describe a theoretical framework which forms the foundation for the development of the aircraft maintenance operations performance assessment model (AMOPAM). The third section will elaborate on the actual development of the model and describes KPI's that have been identified and form the main variables of the model. Hereafter, in the fourth section the model will be adapted to a version that is dedicated to the case 'material unavailability at KLM E&M aircraft maintenance' and used to asses different scenarios on their value creating abilities in order to determine if they can be seen as improvement opportunities. The results of this dedicated model will be presented in the fifth section. When the results of the model have been found valid, conclusions will be drawn and recommendations will be given in the sixth section.

# **II. Theoretical Framework**

This section will review the theories of Real Options Analysis and the Value Operations Methodology and discuss till which extent they can be used to assess the performance of aircraft maintenance operations. Furthermore, it will describe KPI's that have been identified for aircraft maintenance operations and the rationale behind the selection. Combining these two theories with the KPI's that have been identified will form the basis for the model.

### A. Real Options Analysis

The theory of Real Options originates from economic theories on pricing assets. The term Real Options was introduced first by Professor Stewart Myers of the MIT Sloan School of Management in 1977. Real Options are used to evaluate decisions under uncertainty by valuing all possible options. Real Options refer to choices on whether and how to proceed with business investments (Smit and Trigeorgis, 2004). Real options can help management make decisions on investments that might be delayed, expanded, abandoned or repositioned.

Smit and Trigeorgis (2004) state that a Real Options framework adds a dynamic perspective to the traditional valuation approach by incorporating the value of flexibility and growth opportunities in an uncertain environment. By using Real Options one limits the risk in decision making by the information it actually knows, and in this way avoids spending time or capital on infeasible projects. Real Options incorporate the *cost of opportunity*, which are the costs or gains incurred when choosing for alternative options.

Corporate Finance theories posits that firms create value by investing in those projects for which the present value of expected cash inflow, V exceeds the required investment outlays, I (Smit and Trigeorgis, 2004). This description of value creation can also be applied in an MRO-environment when evaluating decisions. For example the cash inflow (V) of ticketing revenues of a certain flight, should exceed the total required investment outlay (I) equaling the sum of costs incurred (e.g. kerosene costs, personnel, maintenance costs and landing fees).

This implies the following condition  $\rightarrow NPV = V - I > 0$ 

Latimore (2002) states that Real Options can be categorized into two types:

Growth Options – Give a firm the ability to increase its future business. Examples include R&D, brand development, mergers and acquisitions (M&A), leasing or developing land, or most pertinent – launching a technology initiative.

(1)

Flexibility Options – Give a company the ability to change its plans in the future. Management can
purchase the option to delay, expand, switch uses, outsource or abandon projects.

The second type of Real Options will be most likely to offer opportunities to be used for assessing the performance of aircraft maintenance operations in terms of financial value. The first type of Real Options are considered to be behind the scope of this research and will not be evaluated further in this paper.

Some illustrative examples of Latimore (2002) and Smit and Trigeorgis (2004) will be used in order to depict the advantage of incorporating the value of uncertainty when calculating the *NPV*.

### Example 1: The option to Invest (Latimore, 2002)

In this example, for simplicity reasons the time value of money and opportunity costs will not be incorporated. As first a fictive scenario will be sketched. For example, KLM wants to introduce a new onboard service that customers have to pay for. The initial investment *I* to be made is  $\notin$  150 million. Two scenarios are possible: the launch will be successful yielding  $V^+ = \notin$  400 million, or there is no demand for the new service resulting in V = 0 million. This is illustrated as an option to invest in the binary tree in Figure 2-1.



Figure 2-1: binary tree of the option to invest (source: author)

The expected project value can be calculated as

$$NPV = q \times (V^+ - I) + (1 - q) \times (V^- - I) = 0.5 \times (400 - 150) + (1 - 0.5) \times (0 - 150) = \text{(50 million)}$$
(2-1)

This satisfies condition 1, that NPV > 0, and thus the investment should be taken into consideration.

### *Example 2: The option to stage the initiative (Latimore, 2002)*

To increase flexibility in the decision making for example for the execution of a new onboard service, the investment can be staged down. Now the firm can gain market data before the product will be initially launched. In this example, a regional pilot phase will be performed costing  $\notin$  50 million of the initial investment. The chance of becoming a success is estimated to be 67 % and the chance of failure is estimated to be 33 %.

After the regional test has been performed, the decision has to be made for a full implementation or not. Due to the pilot phase, the chance of becoming a success has risen to 75% and the chance of failure decreased to 25%. The possible gains or losses will not change and result in  $V^+ = \notin 400$  million and  $V = \notin 0$  million. This is indicated in Figure 2-2.



Figure 2-2: binary tree of the stage the investment (*source*: author)

To calculate the expected project value, the following equation will be used:

$$NPV = (1 - q_0) \times (V^- - I_0) + q_0((1 - q_1) \times (V^- - I_1 - I_0) + q_1 \times (V^+ I_1 - I_0))$$
(2-2)

Substituting the values of Figure 2-2 in equation 2-2 yields:

$$NPV = (1 - 0.67) \times (0 - 50) + 0.67((1 - 0.75) \times (0 - 100 - 50) + 0.75 \times (400 - 100 - 50)) = \text{\&83 million}$$
(2-3)

Which implies that the incremental value of the option to stage the investment is  $83 - 50 = \text{\textcircled{}} 33$  million.

## Example 3: The option to defer (Smit and Trigeorgis, 2004)

In case that circumstances are unfavourable (e.g. in case of the above mentioned investment option for an airline, the currency rate is unfavourable), firms may have the incentive to wait to invest until the circumstances offer more clarity on uncertainties. *The option to defer* is particularly important when making an irreversible investment decision under uncertainty (McDonald and Siegel, 1985, Pindyck, 1988, Dixit, 1989).

If management can not disinvest and recover the initial expenditures if events turn out worse than expected, the investment timing decision should be taken with caution and the project should be deferred until it earns a sufficient premium over its NPV. This analogy is illustrated in Figure 2-3.



Figure 2-3: Graphical example of the option to defer (source: Smit and Trigeorgis, 2004)

The curve in Figure 2-3 represents the added value of having the flexibility to defer the decision of investment and is named the expanded NPV ( $NPV^*$ ) by Smit and Trigeorgis (2004). The closer the decision of investment comes to maturity, the more the flexibility value of deferring the decision will decrease. At maturity (i.e., when no further delay is possible) the value of the flexibility equals zero and the expanded NPV equals it conventional NPV, or zero if management abandons the project. This can be summarized in the following equation:

Expanded NPV = NPV<sup>\*</sup> = Max [net present value  $(V_t - I)$ , abandon (0)] (2-4)

It is arguable whether it is always desirable to delay an investment under uncertainty. Besides the advantage of a wait-and-see strategy, project deferral can involve some disadvantages in certain situations. Furthermore, the *option to defer* will result in a cost that has to be taken into account: the time value of money. When the investment will not be made, the capital to invest can be used to bear interest during the time waiting for the decision to be made. It is arguable though if this phenomenon has to be taken into account when applied in the case of aircraft maintenance operations, because in general their duration is not significantly long.

Examples 1 to 3 illustrate that Real Options offer a valuable opportunity to model and quantify flexibility in decision making. Although having an economical nature and incorporating effects as opportunity costs and risk-free rates, simple forms should be applicable to model and quantify financial value creation in aircraft maintenance operations. Most challenging will be to determine the correct values for the probabilities *q*.



Figure 2-4: Illustration of how volatility increases the value of real options (source: Latimore, 2002 amended by author)

4 American Institute of Aeronautics and Astronautics Latimore (2002) argues that contrary to traditional financial valuation techniques, uncertainty increases the value of Real Options. This is because of the following phenomenon; due to a volatile environment, the chance that the value of a project in the future will exceed the investment required increases. This is illustrated in

Figure 2-4, where the left graph has a wide range of possible outcomes, the other with a relatively narrow range. In the former, more volatile scenario, there is a good chance of producing a project with a positive NPV in the future. The latter, more stable scenario has no chance of producing a project with a positive NPV.

The characteristic that the value of Real Options increases in a volatile environment is of importance to be used in a MRO environment. This offers an opportunity to determine the right option affected by the varying demand as described by McAuliffe (2007) in the first section of this chapter.

#### **B.** Value Operations Methodology

The Value Operations Methodology (VOM) as first described by Curran et al. in 2009 had been applied in a variety of aerospace research fields in order to determine the differential value ( $\Delta V$ ). Smulders (2010) reasons that it is much more logical to relate the value of one instance with another, rather than trying to measure absolute value.

Previous research from Curran et al. (2009), Smulders (2010) and Repko (2011) have shown that the VOM is a useful method to analyze the value creation or destruction on different scenarios or states of systems. One of its advantages is that it can incorporate the opinion of different stakeholders, actors or experts on the specific value of both qualitative and quantitative aspects of a current system or design.

The VOM is a deduction from the Multi-Attribute Value-Theory (MAVT) introduced by Keeney (1992), where a value function is determined by summing the individually weighted ( $\lambda_i$ ) attribute value functions ( $v_i(x_i)$ ). Where  $x_i$  represents an attribute of the value function (Repko, 2011).

The VOM introduces the concept of *value levers*, which consist of the sum of specific system characteristics deltas multiplied by the corresponding weighing factors (Curran et al., 2009). The value levers should be determined based on the value objectives of the system. The VOM is described by the following equation:

$$\Delta V(v_1, v_2, \dots, v_n) = \sum_{i=1}^n \lambda_i \frac{v_{i1}}{v_{i0}}(x_1, x_2, \dots, x_q)$$
(2-5)

The differential value model is a function of the separate value elements  $v_1$  to  $v_n$ , which are themselves a function of attributes  $x_1$  to  $x_q$ .

Where the value levers  $\frac{v_{i1}}{v_{i0}}$  can be calculated as follows:

$$\frac{v_{i1}}{v_{i0}}(x_1, x_2, \dots, x_q) = \sum_{p=1}^q \omega_p \frac{(x_{i,p})_1}{(x_{i,p})_0}$$
(2-6)

The 1 and 0 in  $\frac{v_{i1}}{v_{i0}}$  is used to relate two states of a system or design to each other. The value model uses a

reference state as a benchmark (subscript 0) and the data of the future state or design under consideration (subscript 1), where the aim of the value model is to return the value of the state or design under consideration with respect to the benchmark state or design (Curran et al., 2009).

The VOM is divided in a top level equation with the individual weighted groups  $(\lambda_1)$  of objectives and a second level of objectives consisting of the individual attributes  $\left(\frac{v_{i1}}{v_{i0}}(x_1, x_2, \dots, x_q)\right)$ .

Smulders (2010) states that to implement the VOM it is required that each attribute is mutual preferential independent. Mutual preferential dependence is present when the outcome of attribute  $x_1$  does not influence the outcome of  $x_2$  and vice versa (Repko, 2011).

### Weight factor determination

In order to determine the weighing factors of the value function Curran et al. (2009) used the Analytical Hierarchy Process (AHP) known from NASA's Systems Engineering Handbook developed by Saaty. The AHP process is depicted in NASA's handbook as follows:

- *i.* Describe in summary form the alternatives under consideration
- *ii.* Develop a set of high-level evaluation objectives: for example, science data return, national prestige, technology advancement, etc.
- *iii.* Decompose each high-level evaluation objective into a hierarchy of evaluation attributes that clarify the meaning of the objective
- iv. Determine generally by conducting structured interviews with selected individuals ("experts") or by having them fill out structured questionnaires, the relative importance of the evaluations of objectives and attributes through pair-wise comparisons
- v. Have each evaluator make separate pair-wise comparisons of the alternatives with respect to each evaluation attribute. These subjective evaluations are the raw data inputs to a separately developed AHP program, which produces a single figure of merit for each alternative. This figure of merit is based on the relative weight determined by the evaluator themselves
- vi. Iterate the questionnaire and AHP evaluation process until a consensus ranking of the alternatives is achieved

When the above mentioned steps have been performed on all n objectives, the results have to be transformed into an n x n comparison matrix. An example of an AHP comparison matrix is given below.

	Objective 1	Objective 2	••••	Objective <i>n</i>	Eigenvector	CR
Objective 1	w <sub>1</sub> /w <sub>1</sub>	w <sub>1</sub> /w <sub>2</sub>		w <sub>1</sub> /w <sub>n</sub>	v <sub>1</sub>	
Objective 2	$w_2/w_1$	$w_2/w_2$		$w_2/w_n$	<b>v</b> <sub>2</sub>	
••••					•••	
Objective <i>n</i>	$w_n/w_1$	$w_n/w_2$		w <sub>n</sub> /w <sub>n</sub>	v <sub>n</sub>	

Table 2-0-1: Example of an n x n AHP comparison matrix (source: Curran et al., 2009)

The CR in the 6<sup>th</sup> column indicates the Consistency Ratio, which will indicate if there are any significant inconsistencies due to subjectivity of the actors. The CR can be obtained by first calculating the Consistency Index (CI). This is done using equation 2-7.

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{2-7}$$

In which  $\lambda_{max}$  is the largest (real) eigenvalue of the n x n comparison matrix. The eigenvalues can be obtained by using simple elementary linear algebra. The CR can then be calculated by substituting *CI* in equation 2-8.

$$CR = \frac{CI}{RI}$$
(2-8)

Where the Random consistency Index (RI) can be obtained from Table 2-2.

Table 2-2: Random constancy Index values for comparison matrices of size n x n (source: (Curran et al., 2009)) 2 5 7 8 9 10 n 1 3 4 6 0 0 0.58 0.9 1.12 1.24 1.32 1.45 RI 1.41 1.49

In previous research from Curran et al. (2009), Smulders (2010) and Repko (2011) the basic rule that was used, stated that the value of *CR* should not exceed 0.10 to have valid results.

When the weight factors of both the top and second level objectives and its attributes have been determined the value function of the state or design to be benchmarked is ready to be used.

### C. Aircraft Maintenance Operations KPI's

Because the current literature does provide insight in KPI's that are general applicable for aircraft maintenance operations, the KPI's from the case study KLM E&M will form a basis point to derive KPI's from. The aim of this paper is to asses both the operational and financial performance of aircraft maintenance operations, and therefore an attempt will be made to derive the relationship between all KPI's and the costs or revenues. KLM E&M evaluates the performance of its maintenance operations using 5 KPI's, which are the following (Slobbe and Schotman, 2010):

- Operational Deferred Defects
- Extensions on Deferred Defects
- Lead time of its maintenance checks
- Technical cancellations
- Technical dispunctualities

A deferred defect (DD) is a defect that can be deferred, because its impact on the operation of the aircraft is of such a minimal extent that it can be solved in a later stage. Commercial aircraft have a Minimum Equipment List (MEL) that indicates which materials are necessary for the aircraft to be used for operational purposes. Certain materials have an impact of such a minimal extent to the safety or operation of the aircraft that they are not immediately necessary and their repair or replacement can be deferred. Then the MRO-provider can register it as a deferred defect (DD) in the Aircraft Technical Log (ATL). Depending on the operational impact of the material it is assigned a time-limit in which it has to be solved (which can also be infinitely in case of certain materials). An operational DD is a DD that has a negative impact on the operation of the aircraft, for example a damaged seat preventing it to be sold.

An extension on a DD occurs when exceeding its utmost time to be solved (t >  $t_{DD_due}$ ). If this situation occurs, depending on the category, an extension or postponement of the assigned time limit will be requested to solve the relative DD. When an extension is not possible, an AOG situation will occur.

Using the number of DD's as a KPI is an indicator of the ability of the aircraft maintenance provider to solve defects during a maintenance check. Because this is valid for all aircraft maintenance providers it will be used as a general KPI. Hence, only the total number of DD's outstanding will be used and no distinction will be made between operational or non-operational DD's. The 'extension on DD's' is not considered to be a general applicable DD because it is not directly related to the aircraft maintenance operation. Therefore the first KPI that will be used is the number of DD's outstanding. A DD can negatively influence the financial performance of an airline, by preventing certain operations to be executed. An example is a business class seat which can not be sold and can result in missed revenues of over €15,000 per day.

The lead time of maintenance checks is considered to be of major importance for all aircraft maintenance providers and therefore will be used as a KPI. For simplicity it will be called punctuality and is expressed in percentage of the pre-agreed lead-time of the maintenance procedure. When a maintenance procedure is delayed and thus results in punctuality below 100%, the aircraft on which the maintenance is performed will be in an AOG-situation, which can have a significant negative impact on the financial performance. It can result in both a decreased fleet utilization due to the aircraft that can not be used to transport passengers or cargo as planned and possibly less maintenance procedures that can be executed on a yearly basis. This implies that both the MRO-provider and the airliner can be negatively impacted.

When an AOG-situation arises due to a delayed maintenance procedure, it will have one of the three following implications (Greeve, 2009):

- An alternation of the flight schedule shifting the flight schedule so that no flights are delayed. This action cannot always be executed and depends on whether there are other aircrafts available that could serve as an alternative for the original flight;
- Technical dispunctuality In the case that an alternation of the flight schedule is not possible, the flight
  will have to be delayed. Such an event has financial consequences for KLM. Prunet (2007) has estimated
  that delays on European flights cost KLM €49 per minute and €27 per minute on intercontinental flights;
- Technical cancellation If the delay of the flight will proceed too long and no adequate alternatives are available, the flight will be cancelled. Such events can have significant financial consequences depending on the scheduled flight up to approximately € 250.000 for one cancelled flight.

It can be concluded that both technical dispunctualities and technical cancellations can have a negative impact, both on the financial and operational performance of the aircraft maintenance provider and the airline and are therefore considered to be general applicable KPI's for aircraft maintenance operations.

Due to the implementation of improvement philosophies as Lean and Six Sigma, MRO-providers are continuously aiming to decrease their inventory levels. As a result a shift in the material management has been visible and as a result more materials will have to be supplied throughout the Original Equipment Manufacturers (OEM's) or vendors from the aircraft maintenance provider. When a material is necessary to execute the remainder of the maintenance procedure and it can not be delivered within the ground time of the aircraft throughout its conventional channels, it can be ordered at status AOG by the AOG-desk of the aircraft maintenance provider. There are significant ancillary premiums and minimum purchases order prices that airlines, OEM's and vendors charge each other for this urgent service and therefore it also has a negative financial impact in terms of extra costs.

The number of AOG-orders has been found an appropriate indicator of how an aircraft maintenance provider manages its inventory levels (material availability) and its recovery processes in case of material unavailability. This KPI is considered to be valid for all aircraft maintenance providers.

To measure the financial performance of aircraft maintenance providers, it has been found that revenue and costs are most favourable. By combining both the (relative) profit can be calculated. Profit as a standalone metric is not considered to be an acceptable KPI because it is dependent on both revenues and costs and is not unambiguous when used individually. Aircraft maintenance providers are obliged to keep track of their costs and revenues for their annual report and are not bound to specific accounting policies on these metrics. These two KPI's will finalize the KPI's that are general applicable for aircraft maintenance providers to indicate their operational and financial performance. As a result the following seven KPI's have been identified and are considered to be general applicable for all aircraft maintenance providers.

- The number of Deferred Defects outstanding
- Punctuality of the maintenance procedure
- The number of AOG-orders
- Technical dispunctualities
- Technical cancellations
- Costs
- Revenues

These KPI's have been identified to be the seven most important metrics to measure the operational and financial performance of aircraft maintenance operations. In order to compare different companies or processes a specific unit per KPI should be assigned. For example the number of AOG orders or DD's per aircraft, or the revenue per maintenance procedure.

### **III. Model Development**

The two theories that have been reviewed in the previous chapter, together with the seven KPI's that have been identified will form the basis for the AMOPAM. A schematic overview of the modelling process is given in figure A-1 in appendix A.

# A. AMOPAM

A starting point of the VOM is to define the top level objectives. This will be done based on KLM E&M's definition of the Voice of the Customer (VOC) for aircraft maintenance operations, known from the Lean Philosophy (George, 2002, Rampersad and El-Homsi, 2008). KLM E&M's definition of the VOC for aircraft maintenance operations is as follows:

- Aircraft delivered on time
- With a minimum amount of deferred defects
- With minimal ground time
- At the lowest possible cost (not at cost of quality or safety)

It is assumed that these four definitions of value are considered to be valid for all aircraft maintenance providers. These four value definitions can be categorized in three main topics: *network impact* (1: aircraft delivered on time), *aircraft maintenance performance* (2: with a minimum amount of DD's and 3: with minimal ground time) and finally; *economics* (4: at lowest possible costs). These standalone categories are not yet objectives because no goals are assigned to them. The following goals have been assigned:

- Optimize Economics
- Optimize Maintenance Performance
- Minimize Network Impact

These goals are considered to be valid for all companies executing aircraft maintenance procedures. The second level attribute objectives have been derived from the seven KPI's that have been derived. Also a goal will need to be assigned to them. The following table summarizes all top level- and second level objective attributes:

Objective level	Objective	Goal
Fundamental objective	Economics	Optimize
Attribute	<i>Costs</i> [€/ year]	Minimize
Attribute	Revenue [€/ year]	Maximize
Fundamental objective	Maintenance Performance	Optimize
Attribute	Punctuality [%]	Optimize
Attribute	Material DD's [# outstanding]	Minimize
Attribute	AOG-orders [#/ year]	Minimize
Fundamental objective	Network Impact	Minimize
Attribute	Technical dispunctualities [# minutes / year]	Minimize
Attribute	Technical cancellations [# / year]	Minimize

Substituting these results into equations 2-5 and 2-6 results in the following differential value equation:

$$\Delta V = \alpha E \left( \alpha_1 \left( \frac{\text{Revenue}_1}{\text{Revenue}_0} \right) + \alpha_2 \left( \frac{\text{Costs}_0}{\text{Costs}_1} \right) \right) \\ + \beta M \left( \beta_1 \left( \frac{\text{Punctuality}_1}{\text{Punctuality}_0} \right) + \beta_2 \left( \frac{\# \text{DD's}_0}{\# \text{DD's}_1} \right) + \beta_3 \left( \frac{\# \text{AOG-orders}_0}{\# \text{AOG-orders}_1} \right) \right) \\ + \gamma N \left( \gamma_1 \left( \frac{\# \text{Technical cancellations}_0}{\# \text{Technical cancellations}_1} \right) + \gamma_2 \left( \frac{\# \text{Technical dispunctualities}_0}{\# \text{Technical dispunctualities}_1} \right) \right)$$
(3-1)

Please note that the difference in subscripts between the numerator and denominator is caused due to the following requirement on the differential value function:

- If an increase w.r.t. the current situation is favorable: 
$$\frac{\left(x_{i_r}\right)_i}{\left(x_{i_r}\right)_i}$$
 (3-2)

- If a decrease w.r.t. the current situation is favorable:  $\frac{\left(x_{i_{r}}\right)_{*}}{\left(x_{i_{r}}\right)}$  (3-3)

## **B.** Financial Value Determination

All attributes that can be translated into costs or revenues will be used to determine the relative changes in financial value using the theory of Real Options as described in the literature review. The theory of Real Options offers the opportunity to model in uncertainties on future outcomes when for example the exact value of a future state is not known.

A Change-Impact matrix as described by Smulders (2010) will be used to determine the probabilities (q) that a certain upside in terms of revenues of cost decrease can be gained. The scores from this matrix will also be used as an input for the differential value equation as developed in the previous section.

When al changes in revenues and costs are calculated the relative NPV can be calculated indicating if financial value is created (NPV > 0) or destroyed (NPV < 0), when for example two processes or states are compared.

When both the AMOPAM including the equation for the ROA are determined, the values of for example two operations, processes or companies have to be substituted. The results will indicate if operational value is created or destructed (i.e.  $\Delta V > 0$  or  $\Delta V < 0$  respectively) and similar for financial value. These outcomes can indicate if certain designs or processes can be considered as an improvement relatively to a current design or if for example, company A performs better than company B from an operational and financial value perspective on its aircraft maintenance operations.

# IV. Case Study: Material Unavailability at KLM E&M Aircraft Maintenance

The AMOPAM model that has been described will be validated by applying it on a real life case at KLM E&M. Material unavailability is one of the main disturbances of aircraft maintenance procedures. It can have a significant negative impact from both an operational and financial perspective. The AMOPAM will be tested to assess possible improvement opportunities in KLM E&M's in-house recovery processes used in case of material unavailability at its Aircraft Maintenance department. The improvements should be feasible and have a positive cost to benefit ratio.

# A. Problem Statement

Material unavailability during aircraft maintenance procedure can have several causes:

- The material is locally not at stock;
- The part number is not known;
- The material is not available within the necessary time limit.

In case of material unavailability at KLM E&M aircraft maintenance, there are several options that can be evaluated. These are illustrated in figure 4-1.



Figure 4-1: Schematic overview of alternative options to choose from in case of material unavailability at KLM E&M (source: author)

These options will now be generally explicated below:

- I. Buy If the material is not locally available, KLM E&M will seek if the material can be obtained at one of it is OEMs or vendors within the ground time of the aircraft. In case that the material is very critical to the operation of the aircraft and the remaining ground time is limited, an order can be placed by the AOG-desk of KLM, which indicates that a maintenance procedure is or will be delayed. Orders at status AOG are much more capital intensive than conventional orders. A high ratio of AOG orders versus conventional orders placed by an airline is an indicator of relatively low inventory levels compared to other MRO-providers.
- II. Repair Depending on the severity of the damage of the material, the material can be repaired back to its original state at one of the local workshops at KLM E&M if all approved data from the OEM or vendor is available.
- III. Defer –Depending on the operational impact of the material as stated in the MEL, the defect caused by a damaged or missing material can be repaired or replaced during a later maintenance procedure and will be registered as a DD in the ATL with its specific time limit. DD's caused by material unavailability are called 'material DD's'.
- IV. Make Depending on the complexity of the material, the material can be manufactured if the OEM or vendor will grant a license or its permission for it and provides the necessary approved data. This will be done in-house at one of KLM E&M's workshops.
- V. Cannibalize In case that there is another aircraft available not needing the same material (for example when it is in a D-check for 6 weeks) at that moment, the material can be cannibalized (i.e. robbed) from another aircraft. This does imply that cannibalized material from the other aircraft will need to be obtained throughout one of the above mentioned options, or cannibalized again in a later stage.

A comprehensive process analysis has been performed on the current material unavailability recovery processes at KLM E&M using Lean and Six Sigma methodologies in order to identify major variances, wastes or constraints. The major constraints that have been identified where the following:

- There is no overall process owner responsible for obtaining the necessary material when it is unavailable;
- All process steps are executed sequentially and therefore result in an accumulation of lead time;
- The data-gathering and supply for the in-house recovery processes (i.e. manufacturing and closed-loop repair) are now the responsibility of people for whom this task might be too complex and too time consuming to execute;
- The workshops at KLM E&M are not able to operate 24/7, while there can be a 24/7 demand from the Aircraft Maintenance department, which can result in waste of waiting or a supply gap.

Furthermore, a quantitative statistical analysis has been performed on historical performance data in order to calculate the current impact of material unavailability on the aircraft maintenance operations at KLM E&M. Because the data is confidential, only a brief description of the quantitative results will be given:

- The number of material DD's outstanding form approximately 30% of the grand total. These are all caused by the unavailability of material.
- Yearly 3570 AOG-orders are made on average, resulting in significant cost increases due to ancillary fees.
- Wide-Body A-checks can be significantly postponed due to material unavailability which results in a significant amount of missed revenues due to a decreased fleet utilization and less A-checks that can be performed on a yearly basis.
- AOG-situations caused by material unavailability results in approximately 3% of the total sum of technical cancellations and dispunctualities. Although this is not a major number, the financial impact is significant.

# **B. KLM Dedicated AMOPAM Development**

Multiple actors that are involved within the material unavailability recovery processes have been asked to give a rating on the importance of the top level objectives of the AMOPAM. This is done in order to include the different opinions on the KPI's from different perspectives. It has been chosen to include five different actors due to the following reasons:

- Aircraft Maintenance Hangar (VO-H) perspective It is chosen to make a distinction in between the Aircraft Maintenance performed in the hangars (VO-H) and at the platform (VO-P), because there is such a difference in the duration and workscope of their maintenance procedures and therefore a different weighing might be given on the top level objectives.
- MCC (Operations) perspective The Maintenance Control Centre is incorporated because it is
  involved in both the operation of the maintenance procedures and critical decisions on the network.
- Aircraft Maintenance Platform (VO-P) perspective As mentioned previously, the choice is made to make a distinction between the maintenance executed at the platform and in the Hangar to see if the responsible executives rate the top level objective different.
- Workshop perspective Because the workshop are involved in the material recovery processes used in case of material unavailability, it has been chosen to incorporate their rating on the top-level objectives of the value function.
- Network perspective As determined during the material unavailability impact analysis, KLM's network is impacted by material unavailability by creating technical dispunctualities and cancellations. Therefore they are incorporated in the value function.

A scoring system is used ranging from 1 to 10. Where 1 is having negligible impact and 10 is having most significant impact. The results of the ratings of different executives of the above mentioned actors are summarized in table 4-1.

Table 4-1: Results of the rating	gs of all actors on the to	op level objectives	(source: author)
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	Economics	Maintenance Performance	Network Impact
VO-H (H11)	1	10	7
MCC (Operations)	3	8	8
VO-P (Platform)	4	8	10
Workshop	7	4	5
Network	1	10	8

	Total	16	40	38
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Because the AMOPAM will be used at the case material unavailability at KLM E&M, the second level attributes have been slightly adapted for the dedicated KLM AMOPAM. It is chosen to only include the number of material DD's outstanding instead of the number of DD's outstanding in general.

By substituting the values of table 4-1 in a comparison matrix and using the Analytical Hierarchy Process as described in section 2, the individual weight factors can be calculated yielding:

Table 4-2: Weight factors of the top level objectives (source: author)

Economics		Maintenance Performance	Network Impact	
Variable	α	β	γ	
Weight Factor	0.23	0.40	0.37	

The ratings on the second level objectives have been determined based on the impact of material unavailability on the aircraft maintenance operations at KLM E&M as determined in the previously mentioned quantitative statistical analysis that has been performed. Table 4-2 provides an overview of all the ratings that have been determined. For a more comprehensive description and the rationale behind both the top level- and second level attribute objectives, one should refer to earlier work of the author (Goossens, 2011). The same rating system has been used as with the top level objectives, ranging from 1 to 10.

Table 4-3: Overview of the ratings per second level objective attribute (source: author)

Economics		Main	tenance Perf	formance	Network Impact		
Costs	Revenue	Material DD's	AOG- orders	Punctuality	Technical dispunctualities	Technical cancellations	
7	9	5	4	9	3	3	

The values from table 4-3 have been substituted in a comparison matrix and their individual weight factors have been calculated using the AHP. The results can be seen in table 4-4.

Table 4-4: Overview of the weight factors for the	e second level objective attributes (source: author)
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	Costs	Revenue	Material DD's	AOG- orders	Punctuality	Technical dispunctualities	Technical cancellations
Variable	$\alpha_{1}$	$\alpha_{2}$	$\beta_1$	$\beta_2$	$\beta_3$	$\gamma_1$	$\gamma_2$
Weight factor	0.44	0.56	0.28	0.22	0.5	0.5	0.5

Both the values of the top level- and second level objectives have been tested on their consistency using the Consistency Ratio as described in section 3. All values have been found valid based on their values of CR. Therefore, they can be used in the final KLM E&M AMOPAM. This results in the following equation:

$$\Delta V = 0.23E \left( 0.56 \left( \frac{\text{Revenue}_{1}}{\text{Revenue}_{0}} \right) + 0.44 \left( \frac{\text{Costs}_{0}}{\text{Costs}_{1}} \right) \right)$$
$$+0.40M \left( 0.5 \left( \frac{\text{Punctuality}_{1}}{\text{Punctuality}_{0}} \right) + 0.28 \left( \frac{\# \text{ Material DD's}_{0}}{\# \text{ Material DD's}_{1}} \right) + 0.22 \left( \frac{\# \text{ AOG-orders}_{0}}{\# \text{ AOG-orders}_{1}} \right) \right)$$
$$+0.37N \left( 0.5 \left( \frac{\# \text{ Technical cancellations}_{0}}{\# \text{ Technical cancellations}_{1}} \right) + 0.5 \left( \frac{\# \text{ Technical dispunctualities}_{0}}{\# \text{ Technical dispunctualities}_{1}} \right) \right)$$
(4-1)

Most remarkable points when comparing the different individual weight factors is that revenue has a higher rating than costs, due to the significant amount of missed revenues that are caused by material unavailability. Furthermore, another point of interest is the great impact on punctuality of the Wide Body A-checks, which is also translated in significant amounts of missed revenues and ancillary costs. The weight factors of technical dispunctualities and cancellations are similar because it is assumed that their occurrence is in line.

### **C. Solution Generation**

Based on the process analysis that has been performed on the material unavailability recovery processes at KLM E&M aircraft maintenance, four major constraints have been found as described earlier. These constraints indicate that the current state of the system is un-controlled, due to the lack of a process owner and non-dedicated, due to the supply gap from the workshops.

Based on the constraints and wastes as identified in this process analysis, multiple possible solutions have been generated and categorized in three future state scenarios. These are the following:

- *Controlled Escalation Scenario* Within this scenario no changes are made in terms of dedicated capacity or data supply and gathering. Hence, if material unavailability arises, a process owner is responsible for obtaining the necessary material.
- Uncontrolled Dedicated Scenario Within this scenario dedicated capacity at the workshops
  of KLM E&M is added in terms of FTE that can be consulted 24/7 for urgent request for inhouse recovery processes (i.e. repair or manufacturing). Furthermore, a dedicated team is
  assigned responsible for data gathering in supply for the in-house recovery processes. This
  results in a yearly cost increase. Hence, the term uncontrolled implies that there is no overall
  process owner responsible for the necessary material.
- Controlled Dedicated Scenario- Within this scenario dedicated capacity at the workshops of KLM E&M is added in terms of FTE that can be consulted 24/7 for urgent request for inhouse recovery processes (i.e. repair or manufacturing). Furthermore, a new dedicated team is assigned responsible for data gathering or supply for the in-house recovery processes. This results in a yearly cost increase that is higher than in the previous scenario. Due to these changes the alternative options can be executed in parallel resulting in a possible decrease in overall lead times.

All three scenarios are summarized in the matrix illustrated in figure 4-2.



Figure 4-2: Matrix indicating different scenarios for the in-house recovery processes (source: author)

All three scenarios are evaluated with a Change-Impact matrix evaluated using the Better-Faster-Cheaper paradigm as introduced by NASA in the 1990's. For a more comprehensive explanation of this system one should refer to the earlier work of Smulders (2010). The following six different impact levels with their accompanying numerical values will be used:

Impact Strength	Value	Definition
Low-	-2	The scenario drives the affected attribute slightly downwards
Med-	-5	The scenario drives the affected attribute downwards
High-	-7	The scenario drives the affected attribute strongly downwards
Low+	2	The scenario drives the affected attribute slightly upwards
Med+	5	The scenario drives the affected attribute upwards
High+	7	The scenario drives the affected attribute strongly upwards

Table 4-5: Definition of process impact types (source: Smulders (2010), amended by author)

When the scenario has no or negligible impact on the attribute, the value 1 will be used for mathematical purposes. In terms of percentages the following rule will be applied:

- A scenario having a Low (+ or -) impact corresponds to a 20 % impact on the feasible range of the attribute value (besides the ancillary costs of the scenario)
- A scenario having a Med (+ or -) impact corresponds to a 50% impact on the feasible range of the attribute value (besides the ancillary costs of the scenario)
- A scenario having a High (+ or -) impact corresponds to a 100 % impact on the feasible range of the attribute value (besides the ancillary costs of the scenario)

Smulders (2010) argued that it can be very challenging to rate certain impacts of processes (scenarios), when not being an expert in that specific field. To determine the exact amount of these values would result in massive amounts of extra research and data gathering and is therefore out of the scope of this research. The aim is to qualitatively determine the impact of the scenario on the attribute value and then estimate its impact on its current attribute score using the above illustrated rule. These values will finally be used in the AMOPAM and the impact scores will be used for a Real Options Binominal Tree Analysis. The results of the scores of the Change-Impact matrix on all three scenarios can be found in appendix B.

### V. Results

Based on the quantitative statistical analysis of the material unavailability impact, its current impact has been analyzed. Furthermore, measurements have been performed in order to determine the current ratio of material unavailability issued that are resolved in-house using the in-house recovery processes (i.e. manufacturing or repair). It has been found that this ratio is currently 4.9 %. Two more possible ratios have been assumed based on possible future expectations of the improvements of the in-house recovery processes; a moderate future ratio (10%), and a positive future ratio (15%). These will be used as an input for the AMOPAM model.

Before an output of the model can be calculated, feasible ranges of all second level objective attributes must be determined. This has been done based on the results of the quantitative analysis of the material unavailability impact at KLM E&M and the possible in-house improvement ratios. The actual values are based on confidential KLM figures and therefore a fictive dataset will be used. An example is given in table B-2 in appendix B. Please note that these values do not exactly correspond to the results (in terms of NPV) that will be presented in the remainder of the section.

### A. Controlled Escalation Scenario

The necessary investment outlay (*I*) for this scenario equals  $\in 0,-$ . The Change-Impact matrix in appendix B-1 has shown that the impact on costs and revenue are estimated to have an impact of 50% of the possible maximum achievable improvements. This value will be used for the first probability ( $q_0$ ) in the binominal tree as described in section 3.

Substituting all values in the AMOPAM yields the following results. The changes per each individual attribute can be seen in figure C-1 in appendix C. Please note that the values of  $\Delta V$  are real value and the NPV values are fictive due to the confidentiality of KLM E&M's financials.



Figure 5-1 (left):  $\Delta V$  for different in-house ratios for the controlled escalation scenario (source: author) Figure 5-2 (right): NPV for different in-house ratios for the controlled escalation scenario (source: author)

All ratios satisfy the condition that NPV > 0, and thus that the investment option should be taken into consideration. In this case no investments ( $I_0$ ) will have to be made and the NPV is created by improvements within the system. Please note that this is a fictive cash inflow and is actually created by cost savings or a decrease in missed revenues.

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### **B. Uncontrolled Dedicated Scenario**

Within this scenario, the number of AOG-orders are impacted and therefore taken into account. Because of the capacity that is added, the yearly costs will increase with a yearly amount, which is used as the investment outlay for this scenario ( $I_0$ ).

Because there is dedicated capacity at the workshops of KLM E&M, the number of material DD's and AOG-orders will decrease. Therefore these will also be taken into account when calculating the financial value figures. The changes per each individual attribute can be seen in figure C-2 in appendix C. The results in terms of NPV and  $\Delta V$  can be seen in figure 5-3 and 5-4.



Figure 5-3 (left):  $\Delta V$  for different in-house ratios for the uncontrolled dedicated scenario (source: author) Figure 5-4 (right): NPV for different in-house ratios for the uncontrolled dedicated scenario (source: author)

In case of all in-house ratios, it does not satisfy the condition that the NPV >0 and thus this investment (cost increase) should not be taken in consideration. If the improvements will result in a higher in-house ratio, the NPV will become positive, but relatively low compared to the first scenario which did not need ancillary investments. Therefore this scenario is not considered to be a feasible alternative for KLM E&M.

### C. Controlled Dedicated Scenario

This scenario result in an extra investment outlay of the dedicated role / function created to evaluate alternative in-house options and providing all necessary data. This results in an extra yearly cost greater than the previous scenario. Furthermore, this scenario is expected to create a maximum impact on all attributes and therefore  $q_0$  has a value of 1.0. The probability  $(q_1)$  that a technical cancellation can be prevented is based on the chance that the necessary material can be repaired or manufactured in-house within the necessary time-limit and corresponds to the in-house ratio. The changes per each individual attribute can be seen in figure C-3 in appendix C. The results in terms of NPV and  $\Delta V$  can be seen in figure 5-5 and 5-6.



Figure 5-5 (left):  $\Delta V$  for different in-house ratios for the uncontrolled dedicated scenario (source: author) Figure 5-6 (right): NPV for different in-house ratios for the uncontrolled dedicated scenario (source: author)

The NPV with the in-house ratio of the current state is not positive, hence shows an extremely steep increment when increased. Furthermore, the values of  $\Delta V$  are significantly higher than those of the other scenarios. This is caused by the positive improvements on all KPI's as illustrated in figure C-3.

### **D.** Financial and Operational Value Combination

Figure C-4 in appendix C represents a combination of all results per scenario and different in-house ratio. As discussed previously, the uncontrolled dedicated scenario will not be taken into account due to its negative values of NPV. The controlled dedicated scenario clearly outperforms in terms of differential value, due to its improvements on all KPI's and possible highest value in terms of NPV, when the future in-house ratio will increase.

The relationship between the in-house ratios and values of NPV per different scenario is illustrated in figure 5-7. Most remarkable is the steepness of the controlled dedicated scenario, which indicates that when the in-house ratio increases, the controlled escalation scenario will become a clear outperformer in terms of NPV.



Figure 5-7: Plot of NPV per different scenario and in-house ratio (source: author)

From a scientific point of view it is interesting to determine if there is a relationship between differential (operational) value ( $\Delta V$ ) and financial value (NPV). Therefore a regression analysis has been performed based on the outcome of the value model. The result can be seen in figure 5-8.



Figure 5-8: Regression analysis of the results of NPV versus  $\Delta V$  (source: author)

The value of  $R^2$  does not indicate a significant correlation between the two variables, hence it can clearly be seen that the NPV increases when the  $\Delta V$  increases. In order to gain more insight a more comprehensive dataset should be generated in order to draw concise conclusions.

### **E. Final Remarks**

All alternative scenarios are generated with the aim to create value for KLM E&M's aircraft maintenance department and therefore no negative values of  $\Delta V$  have been seen in the results from the value model. By assessing three different scenarios on their value creating abilities, more insight was gained on their value creating abilities and changes on all second level objective attributes.

The outcome of the AMOPAM has indicated that all three scenarios resulted in an increase of value for KLM. The controlled dedicated scenario was a clear outperformer on all attributes. When the choice is made for

the controlled escalation scenario no ancillary expenditures are necessary, but also no significant operational improvements will be gained.

In terms of NPV, the controlled escalation scenario scored better on the first two in-house ratios. It was shown that the NPV increase of the controlled dedicated scenario was considerably higher when the in-house ratio will improve. Combined with the significant increases in terms of  $\Delta V$ , it is advised to KLM E&M to implement the controlled dedicated scenario in the future.

When assuming the positive future state in-house ratio the following improvement can possibly be gained in the future: a 10.4% increase of value can be achieved. This value is composed by a (i) 1.02% increase in revenue, (ii) 0.70% decrease in costs, (iii) 10.96% decrease in material DD's, (iv) 17.65% decrease in AOG-orders at Hangar 11, (v) 0.89% increase in punctuality at Hangar 11, (vi) 17.65% decrease in technical dispunctualities and cancellations. The exact amount value of the NPV is confidential but can have a significant positive result on KLM E&M's financial results.

The result of the model has been presented to the management of KLM E&M and the advice to choose for the controlled dedicated scenario will be implemented in the near future. This supports the validity and applicability of the AMOPAM.

# VI. Conclusions

This section will finish the paper with overall conclusions on the development of the AMOPAM and provide recommendations for future research. A theoretical framework for the conceptual model has been developed based on the theories of the Value Operations Methodology and Real Options Analysis. This combination has not been previously described in the current literature and has been found a powerful combination in order to assess both financial and operational value creating abilities.

The model has been adapted to assess the performance of aircraft maintenance operations by including seven Key Performance Indicators that have been identified and found valid to be general applicable for all aircraft maintenance providers in order to measure its operational and financial performance. The KPI's that have been identified are (i) costs, (ii) revenue, (iii) deferred defects outstanding, (iv) AOG-orders, (v) maintenance check punctuality, (vi) technical dispunctualities and (vii) technical cancellations.

In order to test the validity of the model it has been applied to the real-life case material unavailability at KLM E&M. Hereby a dedicated version of the AMOPAM has been developed, where the input variables have been slightly adapted. Furthermore, multiple actors involved have given an importance rating on the seven KPI's that have been identified. Together with the results of a quantitative statistical analysis, weight factors have been assigned to all top level objectives and second level objective attributes.

The final model has been used to evaluate multiple future state scenarios on their operational and financial value creating abilities in order to asses if they can be considered as improvement opportunities. The model has shown that the controlled dedicated future state scenario is a clear outperformer in terms of added financial and operational value. Based on the results the advice is given to KLM E&M to implement this future state scenario.

On the data set of all values of NPV and  $\Delta V$  that have been generated for KLM E&M a regression analysis has been performed to determine the relationship in between the two. The value of 0.382 of R<sup>2</sup> does not indicate a significant correlation between the two variables, hence it can clearly be seen that the NPV increases when the  $\Delta V$  increases. This is an interesting phenomenon and it is advised to perform more future research on it with a more comprehensive dataset.

The KLM dedicated AMOPAM has been found a useful tool to evaluate the future state scenarios at KLM E&M. To improve the quality of this model it is recommended to test it at other MRO-providers to gain insight in how the model responds in different environments. Furthermore this will show if the KPI's that have been identified are applicable at all MRO-providers, or if KPI's are missing or can be neglected.

The combination of Real Options Analysis together with the Value Operations Methodology has proven to be a useful combination at the case at KLM E&M. It is advisable to also test this combination in other fields of research to gain more insight in their interaction and interrelation.

# Appendix A



Figure A-1: Schematic overview of the modeling of the performance model for KLM (source: author)

# Appendix B

		Econo	omics	Maintenance Performance		Network Impact		
Scenario Name	Change of Process	Costs	Revenue	Material DD's	AOG Orders	Punctuality	Technical dispunctualities	Technical cancellations
Controllod	Faster					Med + (5)		
Ecolotion	Cheaper	Med +(5)	Med + (5)					
Scanario	Better			No impact (1)	No impact (1)		Med + (5)	Med+ (5)
Scenario	Total Score	5	5	1	1	5	5	5
Uncentrelled	Faster					Low + (2)		
Dedicated	Cheaper	Med - (-5)	Low+ (2)					
Seconaria	Better			Med+ (5)	Med+ (5)		Low+ (2)	Low+ (2)
Scenario	Total Score	-5	2	5	5	2	2	2
Controlled	Faster			Med+ (2)		High+ (7)		
Controlled	Cheaper	High - (-7)	High+ (7)					
Seeparie	Better			Med+ (5)	High+ (7)		High+ (7)	High+ (7)
Scenano	Total Score	-7	7	7	7	7	7	7

Table B-1: Results of the scores of the impact of the different scenarios on the attribute values (source: author)

## Table B-2: Future state value for all second level objective attributes per scenario (source: author)

		Economics		Maintenance Performance			Network Impact	
Scenario Name	Ratio	Costs	Revenue	Material DD's	AOG Orders	Punctuality	Technical dispunctualities	Technical cancellations
Controlled	Current state	€ 120,000	€ 5,000,000	500	3000	75.00%	4000	2.10
Escalation	Future moderate	€ 115,000	€ 5,100,000	500	3000	75.20%	3950	2.05
Scenario	Future positive	€ 100,000	€ 5,200,000	500	3000	75.40%	3900	2.00
Uncontrolled	Current state	€ 120,000	€ 5,000,000	500	3000	75.00%	4000	2.10
Dedicated	Future moderate	€ 118,000	€ 5,050,000	490	2950	75.10%	3975	2.07
Scenario	Future positive	€ 116,000	€ 5,100,000	480	2900	75.20%	3950	2.04
Controlled	Current state	€ 120,000	€ 5,000,000	500	3000	75.00%	4000	2.10
Dedicated	Future moderate	€ 105,000	€ 5,150,000	480	2900	75.50%	3900	2.00
Scenario	Future positive	€ 90,000	€ 5,300,000	460	28000	76.00%	3800	1.90



Figure C-1: Percentage change per second level objective attribute for the controlled escalation scenario (source: author)



Figure C-2: Percentage change per second level objective attribute for the controlled escalation scenario (source: author)



Figure C-3: Percentage change per second level objective attribute for the controlled escalation scenario (source: author)

### Results per Scenario and In-house Ratio



Figure C-4: Overview of the results of both NPV and  $\Delta V$  for all different scenarios and in-house ratios (source: author)

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