# Lifecycle Cost oriented Evaluation and Selection of Product-Service System Variants

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**Abstract**

The markets of capital goods manufacturer are dynamically changing throughout the last years. Offering Product-Service Systems (PSS) provide a promising starting point to obtain competitiveness and to realize the changed customer demands. For fulfilling the demands by PSS, an individual PSS-configuration is necessary. After this configuration process several PSS-variants are available.

The customers' investment decisions for one of these variants are mainly based on the comparison of the purchase costs, neglecting other costs, which arise over the PSS-lifecycle. Thus, for supporting the customers, the paper presents a concept for evaluating and selecting the suitable PSS by a Lifecycle Cost Indicator.

**Keywords**

Product-Service Systems, Lifecycle, Cost

## 1 INTRODUCTION

The markets of capital goods manufacturer are dynamically changing throughout the last years. Due to the cumulative merging of regional to international markets local manufacturers have to cope with an increasing amount of competitors [1]. Additionally, customers of the capital goods manufacturer are increasingly expected to be provided with holistic solutions [2]. In the capital goods industry these solutions consist of a physical product core enhanced by mainly non-physical services [3] combined in a system that deliver value in use [4]. Thus, Product-Service Systems (PSS) represent an approach for tailoring specific solutions which offer the ability to satisfy individual customer needs. Also the competitiveness of capital goods manufacturer can be enhanced [5]. In order to fulfill the customer needs by suitable PSS, an individual configuration of PSS is necessary. After this configuration process several PSS-variants are available. Further on, the customers' investment decisions for one of the offered variants have to be support by economical key figures.

## 2 CONFIGURATION OF PSS

Generally a configuration is defined as a process that enables the compilation (selection and combination) of pre defined physical components. Thereby, a component is described by a set of properties and shows decisive dependencies on other components. These dependencies are represented by the configuration rules [6]. Transferring this definition to the PSS-configuration means that configuration methods need to be extended, because of the characteristics of the non-physical components [7]. Thus, beyond the physical components also non-physical components have to be selected and combined. However, configuration of physical products is different to configuration of PSS. First, the existing interrelations of physical and non-physical components have to be taken into account. Additionally, the individual needs resulting from the customer specific product lifecycle have to be considered when the PSS is configured. An approach which is coping with these challenges has been developed by Aurich in 2007 [5]. At the end of a PSS-configuration process several PSS-variants exist which fulfill the needs of the customer. Up to now the investment decision for one of these variants is mainly based on the purchase costs [8]. However, the purchase costs of PSS in the capital goods industry determine just 10-50% of the whole costs arising over the entire PSS-lifecycle. The overall costs are called lifecycle costs (LCC) [9]. As a consequence, it is possible that the PSS-variant with the lowest purchase costs is not the one with the lowest lifecycle costs. Hence, the investment decision should be aligned at the LCC [10].

## 3 TOWARDS LIFECYCLE COSTS

For assessing the costs arising throughout the whole lifecycle the method of lifecycle costing was developed in the USA – initially for calculating the economic feasibility of complex, large-scaled projects in industrial plant construction [11]. For evaluating the costs the lifecycle has to be divided into the different lifecycle phases. Referring to the German VDI-guideline 2884 the lifecycle from the customers' point of view comprises the investment phase, the utilization phase and the disinvestment phase [12]. Within these phases there are different cost types that have to be considered, e. g. purchase costs, installation costs, operation costs, maintenance costs and recycling costs [13]. Each of these cost types can be decomposed into different sub-cost types. This decomposition is known as a cost breakdown structure [14]. Regarding to the individuality of PSS the LCC depends on different customer specific lifecycle characteristics. These lifecycle characteristics are used to describe the PSS-application, the environmental conditions during utilization, the intensity with which the PSS is used and the overall lifespan of the physical product core. Only if detailed information of the just mentioned characteristics is available a calculation of the exact LCC is possible. Up to now, it is hard to get these characteristics and to find an algorithm which can process them. Thus, a calculation of the LCC can not be realized.

## 4 CALCULATION MODEL FOR THE LIFECYCLCE COST INDICATOR

Consequently, the customers have to be supported by an adequate indicator to prevent one-sided investment decisions. This indicator – called lifecycle cost indicator (LCCI) – supports the customers by evaluating and selecting the suitable PSS. Although the LCCI does not represent the value of the real lifecycle cost, it enables a holistic investment decision.

Based on the described situation the following section presents a model for calculating the LCCI. The model is divided into four steps. These steps are “Identification of main cost types”, “Identification of cost determining factors”, “Identification of cost determining factor-combinations” and “Comparison and evaluation of cost determining factor combinations”.

### 4.1 Identification of main cost types

This step aims at the identification of the application-specific main cost types (MCT). Therefore, all costs that arise throughout the PSS-lifecycle have to be identified. Furthermore, the amount of these costs compared to the LCC has to be estimated qualitatively. Expert interviews are used to determine the cost types for each lifecycle phase and to estimate the share of these costs to the LCC. For example, experts for the utilization phase are the service technicians and the customer. Typical cost types of this phase are maintenance costs or storage costs. Three different categories are available which can be used to describe share of the costs to the LCC. A decisive cost type makes either a high (++), a middle (+) or a low (o) share of the LCC. The cost types that seem to have a high share are defined as application-specific MCT (Figure 1). Only the MCT are used to calculate the LCCI. The choice of the MCT is conducted due to the Principle of Pareto which means that 80% of the LCC are determined by 20% of the cost types. Thus, the costs that are not defined as MCT could be neglected.

### 4.2 Identification of cost determining factors

The amount of costs arising within a specific MCT is influenced by different factors. These factors are named cost determining factors (CDF). CDF are properties that could be assigned to the physical and non-physical PSS-components as well as to specific lifecycle characteristics. For example, the choice of a ductile tool will lead to high wear effects when it is applied in high abrasive environment. Due to this, a shortened lifespan and consequently increasing repair costs could be expected. The goal of this step is to identify the CDF of the previously defined MCT.

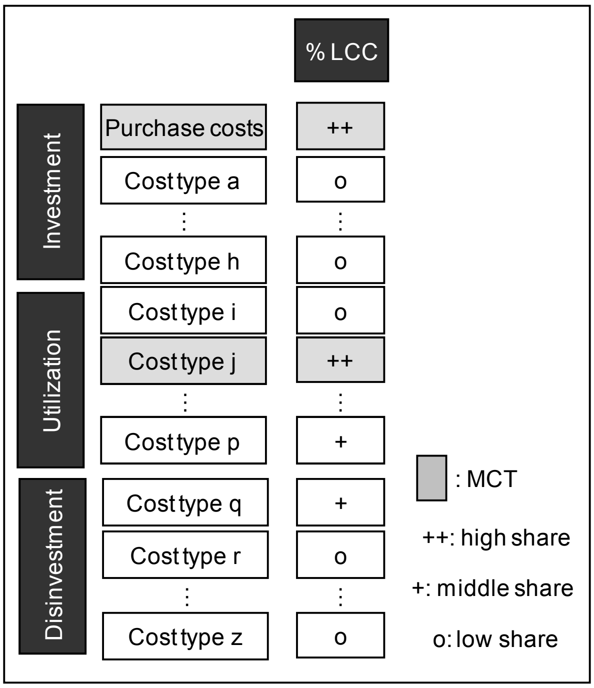



Figure 1: Phase-specific cost type list.

For identifying the CDF a matrix is used. This matrix contains all MCT (vertical line) and the identified CDF (horizontal line) (Figure 2).

In each cell the influence of the CDF to the regarded MCT has to be assessed. Three categories are available for assessing the influence – strong (++), middle (+) and weak (o) influence. A strong influence means that the value of the MCT strongly depends on the chosen CDF. If a CDF is assigned to have middle influence, the CDF shows a principle influence on the MCT, but in very low level. If no or just a marginal influence is expected, then the appropriate cell has to be marked with the symbol for a weak influence. The most important CDF for calculating the LCCI can also be identified according to the Pareto principle. Only these CDF are used in the following steps.

### 4.3 Identification of CDF-combinations

In the third step all possible combinations between the different CDF are generated. Therefore, the different values of each CDF have to be defined and documented. For example, a CDF for a physical component (PC 1) could be the width of the product. Concerning a cm-scale

| | | % LCC | Physical components | | | | Non-physical components | | | | Lifecycle characteristics | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | PC1 | PC2 | ⋮ | PCn | NPC1 | NPC2 | ⋮ | NPCm | LC1 | LC2 | ⋮ | LCp |
| Investment | Purchase costs | ++ | + | o | ⋮ | ++ | o | o | ⋮ | o | ++ | ++ | ⋮ | + |
| | Cost type a | o | o | o | ⋮ | o | + | + | ⋮ | o | o | o | ⋮ | + |
| | … | … | … | … | | … | … | … | | … | … | … | | … |
| | Cost type h | o | o | o | ⋮ | o | o | o | ⋮ | o | + | o | ⋮ | o |
| Utilization | Cost type i | o | o | ++ | ⋮ | + | o | + | ⋮ | o | o | o | ⋮ | + |
| | Cost type j | ++ | ++ | o | ⋮ | + | ++ | + | ⋮ | o | ++ | o | ⋮ | + |
| | … | … | … | … | | … | … | … | | … | … | … | | … |
| | Cost type p | + | o | o | ⋮ | ++ | o | + | ⋮ | o | o | ++ | ⋮ | + |

++: strong influence +: middle influence o: weak influence

Figure 2: Matrix of the CDF.

| | Utilization – Cost type 2 | | | | | |
|---|---|---|---|---|---|---|
| | CDF 1 = PC 1 | | CDF 2 = NPC 1 | | CDF 3 = LC 2 | |
| | Class 1 | Class 2 | Class 1 | Class 2 | Class 1 | Class 2 |
| Combination 1 | X | | X | | X | |
| … | … | | | | | |
| Combination n | X | | | X | X | |

Figure 3: Possible CDF-combinations.

by covering a width of 1,40m to 2,00m 60 different values are possible. Thereby, the quantity of combinations depends on the amount of possible values of a CDF. Because of this the quantity of combinations could increase exponentially. For reducing this quantity, several CDF values have to be classified. Regarding the mentioned width of a product the following classes could be generated:

- Class 1: 1,40 – 1,50m
- Class 2: 1,51 – 1,90m
- Class 3: 1,91 – 2,00m

A class has to be heterogeneous in contrast to other classes and homogeneous concerning the class itself. That means that the CDF-values within one CDF-class should affect the LCCI in the same way. The CDF-classes however should affect the LCCI differently. Because of this, the classification should also be done by experts. The result of the classification is a defined number of classes for each of the CDF. Based thereon, the combination is conducted concerning these CDF-classes (Figure 3).

### 4.4 Comparison and evaluation of CDF-combinations

Creating the scheme for calculating the LCCI is the aim of the last step. The influence of each combination of the previous step to the regarding MCT has to be relatively assessed to the other combinations. The comparison is conducted pair wise. Comparing a combination with another one, the following statements are possible:

- One of the combinations leads to lower or higher MCT (mark with “-1” or “1”)
- Both combinations lead approximately to the same MCT (mark with “0”) (Figure 4)

After the comparison of each possible pair, the relative weights representing the expected level of influence on the MCT for each combination could be calculated. Based on the relative weights, a ranking of the combinations could be derived.

Further on, based on this ranking combination-specific cost rates could be calculated. Therefore, the definition of an operating time depending factor – e. g. operation hours or driven kilometers – is necessary. In addition, regarding to this factor, the cost rate for the most ($CR_{max}$) and less ($CR_{min}$) cost intensive combination has to be calculated or estimated, respectively. Based on these costs and the calculated relative weights (see Figure 4) the cost rates for the remaining combinations are calculated by the following equation:

$$CR_x = CR_{min} + (W_x - W_{min}) \cdot \frac{(CR_{max} - CR_{min})}{(W_{max} - W_{min})} \quad (1)$$

where $CR_x$ is the cost rate of combination x; $CR_{min}$ and $CR_{max}$ is cost rate of the most and less cost intensive combination; $W_x$ is the relative weight of combination x; $W_{min}$ and $W_{max}$ is the relative weight of the most and less cost intensive combination.

The results of this step are cost rates for the MCT of each application the PSS is used for. The cost rates of every MCT are the basis for calculating the LCCI of all possible PSS-variants suitable to the customer’s lifecycle. The calculated LCCI does not represent the real arising LCC, but supports the comparison of the PSS-variants and therewith the customers’ investment decision.

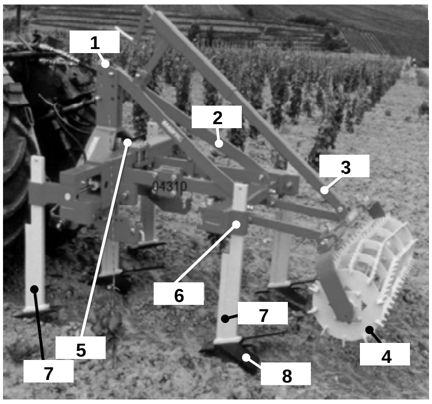
## 5 LCCI-CALCULATION USING THE EXAMPLE OF A CULTIVATOR

A cultivator with a rotary harrow is used for illustrating the

| | Comb. 1 | Comb. 2 | Comb. 3 | Comb. 4 | Comb. 5 | Comb. 6 | Comb. 7 | Comb. 8 | Weight |
|---|---|---|---|---|---|---|---|---|---|
| Comb . 1 | | -1 | 1 | 1 | 1 | 1 | 1 | 1 | 20 % |
| Comb . 2 | 1 | | 0 | 1 | 0 | 1 | 1 | 1 | 20 % |
| Comb . 3 | -1 | 0 | | 1 | 0 | 1 | 1 | 1 | 17 % |
| Comb . 4 | -1 | -1 | -1 | | 0 | 1 | 0 | 1 | 11% |
| Comb . 5 | -1 | 0 | 0 | 0 | | 1 | 1 | 1 | 16 % |
| Comb . 6 | -1 | -1 | -1 | -1 | -1 | | 0 | 1 | 6 % |
| Comb . 7 | -1 | -1 | -1 | 0 | -1 | 0 | | 1 | 8 % |
| Comb . 8 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | | 1 % |

Figure 4: Pair wise comparision of the CDF-class combinations.

suggested concept. The cultivator is a tool for winegrowers basically used for loosen compacted soil (Figure 5). As to operate the cultivator it is usually mounted to a smaller tractor through which also its rotary harrow is propelled. The cultivator might be composed of various components, depending on the environmental conditions and the tasks the customer have to fulfill throughout the lifecycle. Due to this, different physical and non-physical components and therewith different cultivator variants become necessary.




1 - Under Frame 2 - Mounting Frame 3 - 3-Point Mounting
4 - Rotary Harrow 5 - Tool Holder 1 6 - Tool Holder 2
7 - Tool 1 8 - Tool 2

Figure 5: Cultivator with rotary harrow.

The following steps have to be executed for each of the applications the cultivator is used throughout its lifecycle. In this case loosening – as the main application of the cultivator – is underlying the example.

In the first step the MCT are defined by experts of the production development and distribution in cooperation with the customer. Due to this, all cost types are gathered and their shares of the LCC are estimated. Concerning the cultivator the purchase costs, the maintenance costs, the costs for the service technicians, the storage costs and the recycling costs are defined as the relevant cost types. After the qualitative estimation of their share of the LCC purchase costs and maintenance costs are determined as the only MCT. Consequently, the LCCI is only calculated based on these two cost types.

Further on, the purchase costs are neglected, because they only depend on the chosen PSS-variant. The value of the purchase costs is calculated by the chosen physical and non-physical PSS-components. In order to identify the CDF of the maintenance costs, the physical and non-physical PSS-components as well as specific lifecycle characteristics are analyzed. Based on this analysis, the influence of the defined CDF regarding the maintenance costs is assessed. Thereby, the qualitative assessment is also carried out by experts. The following list presents the resulting CDF with its related CDF-classes:

- Tool composition
  - Strongly wearing tools
  - Weakly wearing tools
- Spare part
  - New part
  - Remanufactured part
- Soil type
  - Strongly stressing soil
  - Weakly stressing soil

Afterwards, all possible combinations of the CDF-classes are determined. For example, a strongly wearing tool composition could be used in a weakly stressing soil, whereby the customer chooses new spare parts. In this case there are eight combinations possible (Figure 6).

The next step deals with the comparison and the evaluation of the combinations regarding their influence on the maintenance costs. The combinations are compared pair wise. The underlying question is "Does the combination lead to a longer (1) or shorter (-1) lifespan or is the lifespan for both combinations approximately the same (0)?". For example, when choosing combination 1 (strong wear, new parts, strong stress) a shorter lifespan is expected than choosing combination 2 (strong wear, new parts, weak stress). Hence, the according cell is marked with "-1". After the comparison of all combinations the relative weights of the combinations can be computed. In the example combination 6 gets the highest and combination 3 the lowest weight (Figure 7). That means that the longest lifespan could be expected by choosing combination 6 and the shortest by choosing combination 3, respectively. The next step aims at determining the lifespan. The lifespan of a PSS assigned to combination 3 is estimated by experts with 30.000m and the lifespan of a PSS assigned to combination 6 with 50.000m. Based on these values, the lifespan of all the other combinations could be calculated by using the introduced equation. As cost rate for replacing tools by new tools 1.200,-€ is used.

| CDF | Tool composition | | Spare part | | Soil type | |
|---|---|---|---|---|---|---|
| CDF-classes | Strong wear | Weak wear | New part | Remanuf. part | Strong stress | Weak stress |
| Combination 1 | X | | X | | X | |
| Combination 2 | X | | X | | | X |
| Combination 3 | X | | | X | X | |
| Combination 4 | X | | | X | | X |
| Combination 5 | | X | X | | X | |
| Combination 6 | | X | X | | | X |
| Combination 7 | | X | | X | X | |
| Combination 8 | | X | | X | | X |

Figure 6: All possible combinations of CDF-classes.

| Maintenance costs | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Comb. 1 | Comb. 2 | Comb. 3 | Comb. 4 | Comb. 5 | Comb. 6 | Comb. 7 | Comb. 8 | Weight |
| Comb. 1 | | -1 | 1 | -1 | -1 | -1 | -1 | -1 | 0,05 |
| Comb. 2 | 1 | | 1 | 1 | 0 | -1 | 1 | -1 | 0,16 |
| Comb. 3 | -1 | -1 | | -1 | -1 | -1 | -1 | -1 | 0,02 |
| Comb. 4 | 1 | -1 | 1 | | -1 | -1 | 1 | -1 | 0,11 |
| Comb. 5 | 1 | 0 | 1 | 1 | | -1 | 1 | -1 | 0,16 |
| Comb. 6 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 0,23 |
| Comb. 7 | 1 | -1 | 1 | -1 | -1 | -1 | | -1 | 0,08 |
| Comb. 8 | 1 | 1 | 1 | 1 | 1 | -1 | 1 | | 0,20 |

1: longer lifespan  0: same lifespan  -1: shorter lifespan

Figure 7: Pairwise comparison of the CDF-classes regarding the maintenance costs.

For calculating the LCCI for each PSS-variant with strongly wearing tools and the use of remanufactured parts, additional information about the soil type of the customer is necessary. Only based on this information the appropriate CDF-combination can be identified. Assuming i. e. a strongly stressing soil CDF-combination 7 has to be used for calculating the maintenance costs. The lifespan of a PSS assigned to combination 7 is 35.714m. Considering the calculated lifespan, the intensity with which the customer will use the PSS throughout the lifecycle and the contract duration the resulting value of the maintenance costs are calculated. The LCCI of the dedicated PSS-variant results from the combination of the calculated maintenance costs and its purchase costs.

After the LCCI-calculation for each suitable PSS-variant a ranking is generated, whereas the most beneficial PSS-variants are listed on top (no. 1-3) (Figure 8). Comparing these PSS-variants to the low priced variants with respect to the purchase costs (no. 4-6) an investment decision based on the purchase costs would lead to additional costs of approximately 20%. The case study shows that the LCC oriented selection could gain an economical benefit for the customer. Especially for PSS that cause high costs throughout their lifecycle the calculation of the LCCI is recommended.

## 6 CONCLUSION

The paper shows how a LCC oriented evaluation and selection of suitable PSS is achieved. Therefore, a concept for calculating the Lifecycle Cost Indicator (LCCI) is presented. The calculated LCCI does not represent the real arising LCC, but supports the comparison of suitable PSS-variants. Based on this a holistic investment decision by the customer could be realized.

For calculating the LCCI some preliminary work is required. Section 4 describes this work in a structured sequence. Further on, section 5 illustrates the concept by an example. The results of the example show how a lifecycle oriented view is necessary during the investment decision. Neglecting the costs that arise throughout the lifecycle could cause economical disadvantages.

Future research will spend on key figures that are based on further aspects. These aspects could represent resource- or ecologic-specific figures. Therefore, a concept for combining these figures with the LCCI is necessary. This concept also allows to weight different key figures, so that the different customers' interests could be considered. Hence, a more holistic evaluation and selection of PSS will be possible.

| No. | Physical component | Non-physical component | Purchase costs of the PSS [€] | LCCI [€] |
|---|---|---|---|---|
| 1 | UF (1000-1400mm) + MF (short)+ TL (Plow+SECHE) | 5 year maintenance; 24/7; remanufacture parts | 3.380 | 6.080 |
| 2 | UF (1000-1400mm) + MF (long) + TL (Plow+SECHE) | 5 year maintenance; 24/7; remanufacture parts | 3.480 | 6.180 |
| 3 | UF (1000-1400mm) + MF (short) + TL (Plow+SECHE) | 5 year on-site maintenance; 24/7; remanufacture parts | 3.480 | 6.180 |
| 4 | UF (900 -1300mm) + MF (short) + TL (plow) | - | 2.530 | 7.330 |
| 5 | UF (900 -1300mm) + MF (long) + TL (plow) | - | 2.630 | 7.430 |
| 6 | UF (1000 -1400mm) + MF (short) + TL (plow) | 2 year maintenance; 24/7; remanufacture parts | 2.810 | 7.010 |

UF: Under Frame  MF: Mounting Frame  TL: Tool

Figure 8: Ranking of suitable PSS-variants.

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