VALUE-DRIVEN DESIGN

AN MD3S WORKBOOK

Developing solutions that provide great value to customers and users is the main ingredient of market success. In this workbook you will learn how **to keep focus on value generation** throughout your entire development process for Product-Service Systems.

The workbook targets designers, product developers, systems engineers, managers and business executives who wants to learn how to **work in a systematic way** to map customer needs and values for new products and services, and how to choose the design concept that maximize customer satisfaction and long-term profitability

IN THIS WORKBOOK

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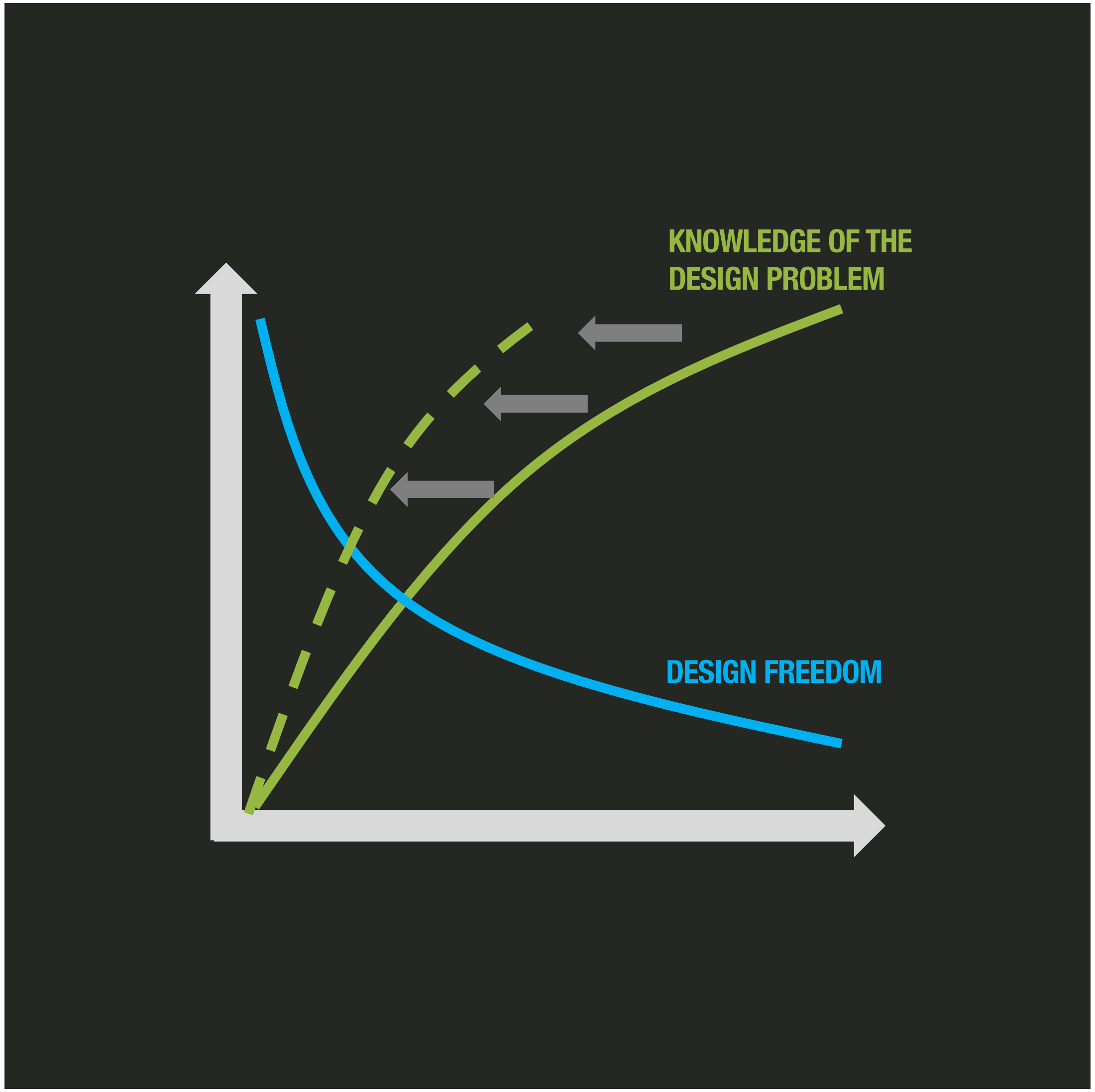
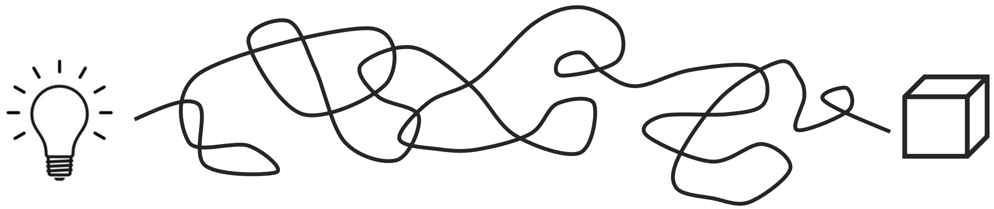
This workbook presents an approach for assessing the value of PSS solutions in the conceptual design stage, together with practical design guidelines to support early product/service development decisions.





INTRODUCTION TO VALUE-DRIVEN DESIGN

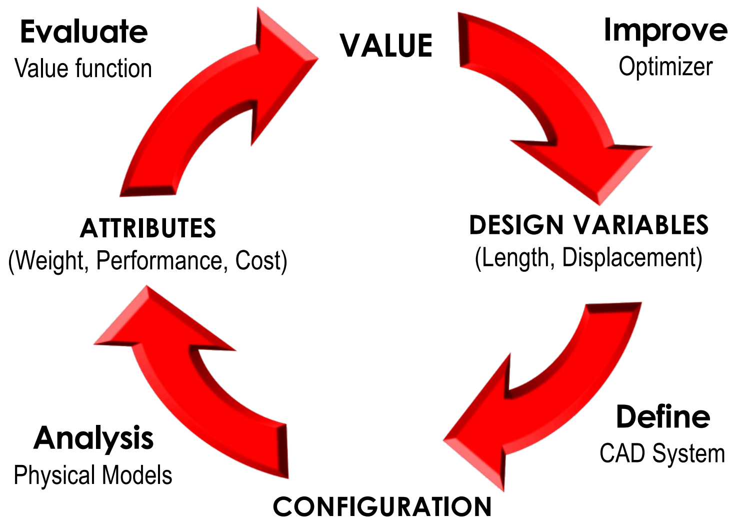
Engineering design today is not as straightforward as it once was. The development of the first aircraft engine in 1903 was mostly a matter of mitigating the risk of torque effects by making propellers rotating in opposite directions. Nowadays, new aero-engine development programs are driven by much more sophisticated considerations, such as 'power-by-the-our', 'predictable cost of ownership' and 'product stewardship'.

Pure mechanical challenges have become a complex trade-off game between technological feasibility, customer desirability and economic viability. Developing successful products today is a matter of being able to map, measure and proactively used these 'value' dimensions as drivers throughout the entire process.

Value-Driven Design (VDD) is a methodology to model and visualize 'value creation' during the earliest stages of the design of a new system, including products, services and software.

So called **'value models**' are the center of the methodology. They are intended to help the engineering team in systematically mapping and measuring customer satisfaction and profitability of new design concepts. Early on in the design process, critical decisions on what to develop are taken based on gut-feeling and intuition.

Through the systematic application of value models it is possible to mitigate the time, cost and risk for rework due to sub-optimal decisions in such early phase.



HOW DOES VALUE-DRIVEN DESIGN WORK?

VDD is often explained as a cycle (Collopy and Hollingsworth 2011). Firstly, designers pick a point in the design space at which to attempt a solution.

Then, they create an outline of the design, which is elaborated into a detailed representation of design variables.

Later, they produce a second description of the design instance, in form of a vector of attributes that mirrors the customer preferences or “value scale”.

These attributes are assessed against an objective function, which accepts such vector as its argument to assign a score to rank a design.

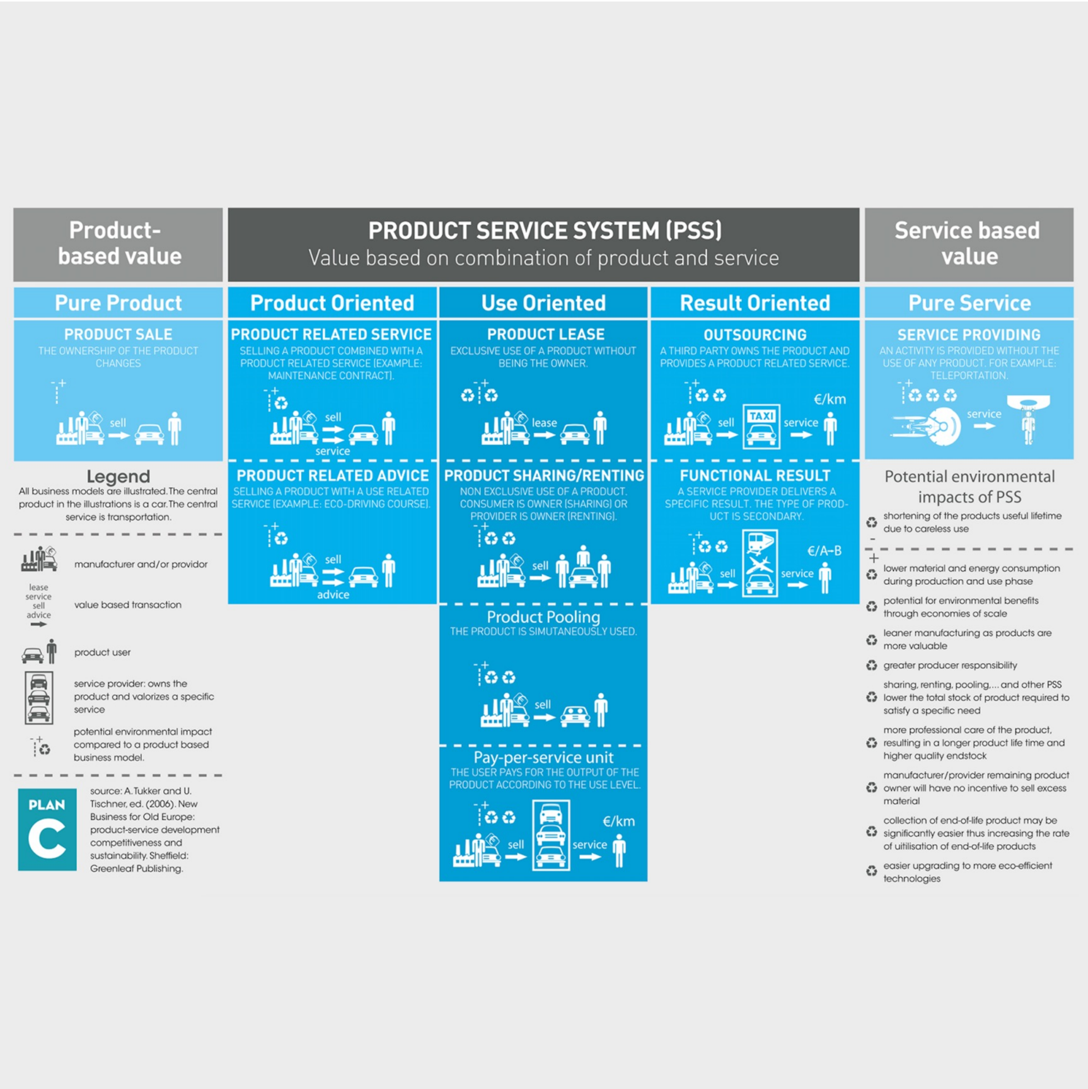
The **“best” design** is one that ultimately produces the **highest score.**

WHY TO USE VALUE-DRIVEN DESIGN?

VDD enables all components and parts of a system to be designed with a view on the **total value generated** within a project.

Local optimal solutions, which are based on the short-range exploration of the design space around a baseline option, are confronted with a much larger amount of possible solutions through the systematic use of models that are able to determine how varying design attributes affect the overall value of a product.

VDD propagates the long-term profitability idea to the systems and sub-systems to enable optimum solution strategies to be instantiated in objective, repeatable, and transparent manner.



Vision

Objective

Driving research question

INTRODUCTION TO MD3S

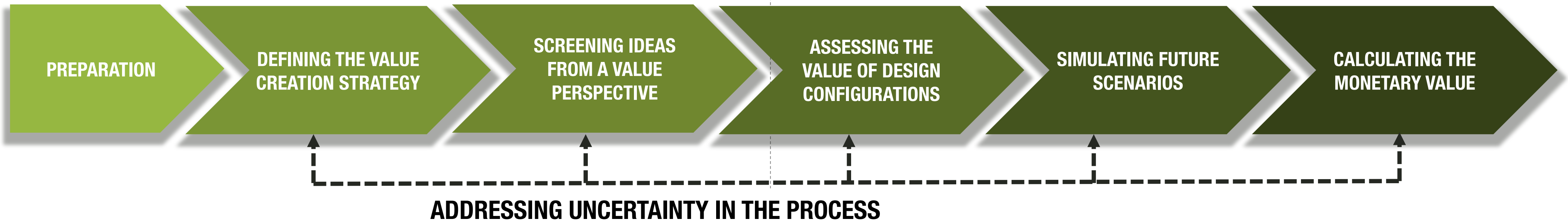
The **Model-Driven Development and Decision Support (MD3S)** research profile is an initiative funded by the Knowledge Foundation in Sweden dedicated to sustainable Product-Service Systems (PSS) innovation.

The vision for MD3S is to become an internationally. leading research environment and the first-hand choice of partners who want to lead the way to a sustainable society through competitive product-service systems supporting a circular economy

Its main objective is to develop, disseminate, and integrate relevant, user-friendly and efficient computer aided support methods and tools for sustainable innovation into business leaders', business developers' and product developers' working environments that enable industry to thrive in the changing global context, supported by both simulated and real data using internet of things and AI/machine learning.

The concept of model-driven means that throughout the development process using models (virtual representation of reality) as communication media it is possible to shorten development cycles and improve multidisciplinary understanding in design.

By also adding capability to collect live data from machines via connected sensors (Internet of Things – IOT) and finding patterns and solutions using big data analytics (including AI and Machine Learning) creating the potential for digital twin approach, the aim is to improve the Key Performance Indicators (time, quality and cost) for design even more .



THE VALUE-DRIVEN DESIGN PROCESS

This workbook describes how to apply the VDD process to support the design of innovative Product-Service Systems. VDD is composed of 8 stages, supported by specific methods and tools.

Stage 0: Preparation
This step wants to provide an understanding of the main dimensions of 'value' that are relevant for engineering and design. The Triple Bottom Line, Value Proposition Canvas and the Design Thinking methodology frameworks are main references in this respect.

Stage 1: Defining the Value Creation Strategy
This step aims at providing a detailed description of the characteristics, motivators and preferences of different markets and customers for the PSS. The Value Creation Strategy framework proposed in this step aims at helping the design team in defining a complete and customized list of value criteria for a new solutions. These criteria are further prioritised to mirror the preferences of a given market/, and consider both a customer and provider perspective. Customer Tier Analysis, Personas and Value Strategy Canvas are the main tools used here to inform the creation of the VCS

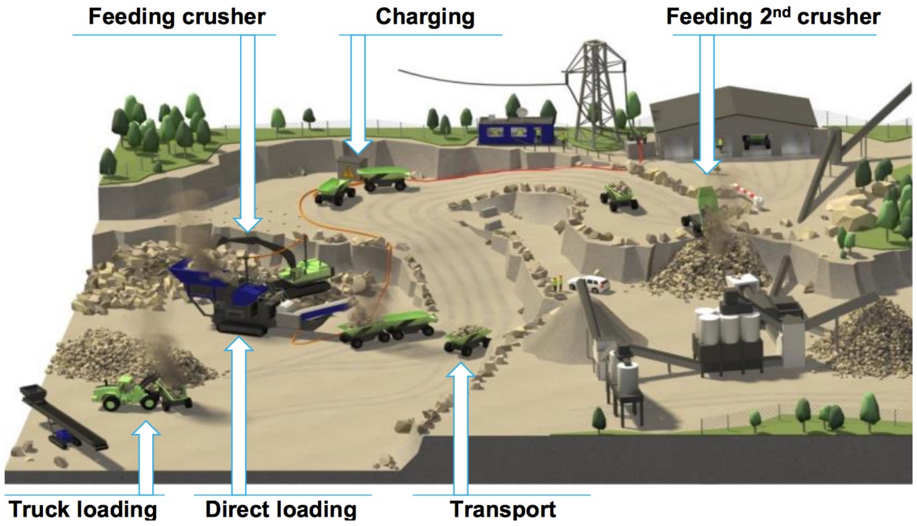
Stage 2: Screening Ideas from a value perspective
This steps provides a systematic, collaborative approach to support the preliminary, iterative screening of innovative ideas in a multidisciplinary setting, using the Pugh and TOPSIS decision making matrixes.

Stage 3: Assessing the value of design configurations
This steps provides a more granular, detailed assessment of the value of alternative PSS design concept configurations. The EVOKE model is a major support tool for this task. It exploits value functions of different shapes and sizes to map the engineering characteristics of a product against the value criteria. This mapping process matrix is informed by an IBIS map.

Stage 4: Simulating future scenarios
This step transports the design team form the realm of qualitative assessment to domain of quantitative analysis. Discrete Event Simulations are used here to calculate the performances of a design concept in alternative lifecycle scenarios.

Stage 5: Calculating the monetary value
Based on the information provided by the previous simulations, the design team at this steps is able to calculate the monetary value (representing long-term profitability) of a proposed solution, both from a provider and customer viewpoint.

Stage 6: Addressing uncertainty in the process
The last step runs in parallel with the activities described above and collects methods and tools to manage uncertainty in the process, so to inform decision makers on of how much the results of the value modelling activities in the different steps can be trusted.



Example: the Electrical Site

The application of the VDD process presented in this workbook is exemplified in a case study related to the development of the Electrical Site concept proposed by Volvo Construction Equipment.

The concept of Electrical Site aims to transform the quarry and aggregates industry by reducing carbon emissions by up to 95% and total cost of ownership by up to 25%

The workbook follows the development of a fully autonomous and electrical vehicle inspired by Volvo The VDD process is applied to explore the value of different product configurations in an early stage, including geometrical dimensions, battery technologies, battery capacity and motor type.

You can read more about the electrical site concept at this link:

https://www.volvoce.com/global/en/this-is-volvo-ce/what-we-believe-in/innovation/electric-site/

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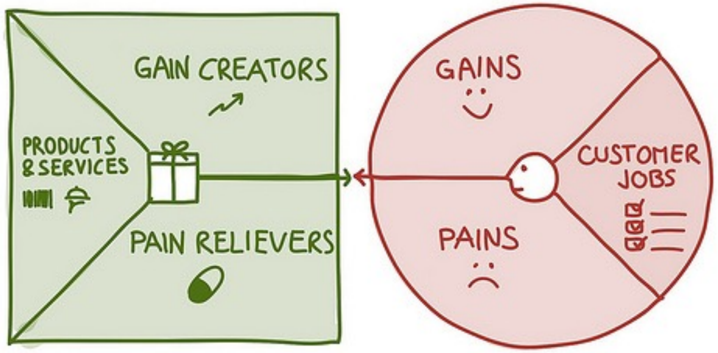
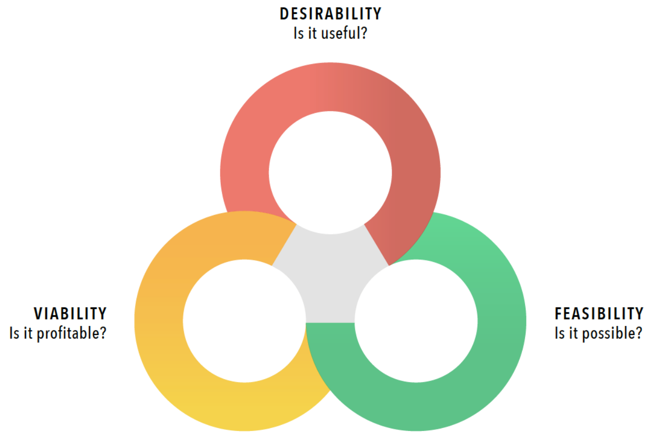
TRIPLE BOTTOM LINE (Elkington 2004)



VALUE PROPOSITION CANVAS (Osterwalder et al. 2014)



DESIGN THINKING (Leavy 2010)

STEP 0: PREPARATION

What will be the outcome?

- An understanding of the main dimensions of 'value' that are relevant for engineering the PSS.

Data-information required

- Only a basic understanding of value theory.

People required

- Possibly the extended design team, including all functions having relevant knowledge about the solution.

0.1. Understanding value creation

When qualitative data and assumptions prevail in the earliest phases of the PDD design process, a qualitative assessment of the 'goodness' of a design is preferable against a monetary-based encoding of preferences.

Product development and engineering design literature often present examples of qualitative criteria for multi attribute decision making which typically precedes more deterministic assessments. A main issue in this respect is how to define a list of 'drivers' that mirrors all important aspects of value for the solutiuon.

Several frameworks have been proposed to systematically raise awareness and understanding in the design team of what 'value' is for new solutions.

0.2. Value-generation frameworks

Several contributions stand out in the quest for a systematic framework from which value metrics can be categorized.

The **Triple Bottom Line** accounting framework, which incorporates 'social', 'environmental' and 'financial' performance dimensions, is a major reference in literature.

Another major contribution to categorise value criteria for design is the **Value Proposition Canvas**, which describes value creation in terms of Customer Gains and Customer Pains. The first gathers customer benefits and desires, spanning personal, functional, or economical dimensions. The latter collects all negative emotions and undesired costs, situations and risk that customers could experience before, during and after getting the job done.

The **Value equation** proposed by Lindstedt and Burenius is inspired by the VPC and defines customer value in the broader perspective of "perceived customer benefit", described in terms of 'main', 'additional', 'supporting' and 'unwanted' functions. The **Design Thinking** methodology provides a further mental model to specify these categories. The intersecting "constraints" in the "feasibility", "viability" and "desirability" (FVD) framework ("what can be done" - "what you can do successfully within a business" – "what people want or will come to want").

Try Out

At the following link you can find examples on how to use the frameworks described above: LINK.

STEP 1: DEFINING THE VALUE CREATION STRATEGY

What will be the outcome?

- A complete list of value criteria with priorities that mirror the preferences of a given market or customer.

Data-information required

- Basic Information about the market/ customer being targeted, together with information on the company strategy.

People required

- The engineering team, the product managers, the marketing team, aftermarket responsible, business representatives.

1.1. .Raising awareness of the value-creation opportunity

Value generation is a major reason why manufacturing companies are moving towards servitized business models. Simply put, PSS can provide more value to customers, compared to traditional solutions.

In order for 'value' to become a major driver for the design process, it is critical to get to know who customers and stakeholders are, and to define with precision what dimensions of value creation are important for them.

The first stage in the VDD process aims to raise awareness about how markets and customers will react to the introduction of new products and services.

Methods and tools at this step intend to bring forward preferences, attitudes and motivators that characterize existing and potential clients. This understanding will drive decision making in the rest of the VDD process.

1.2. Describing the VCS

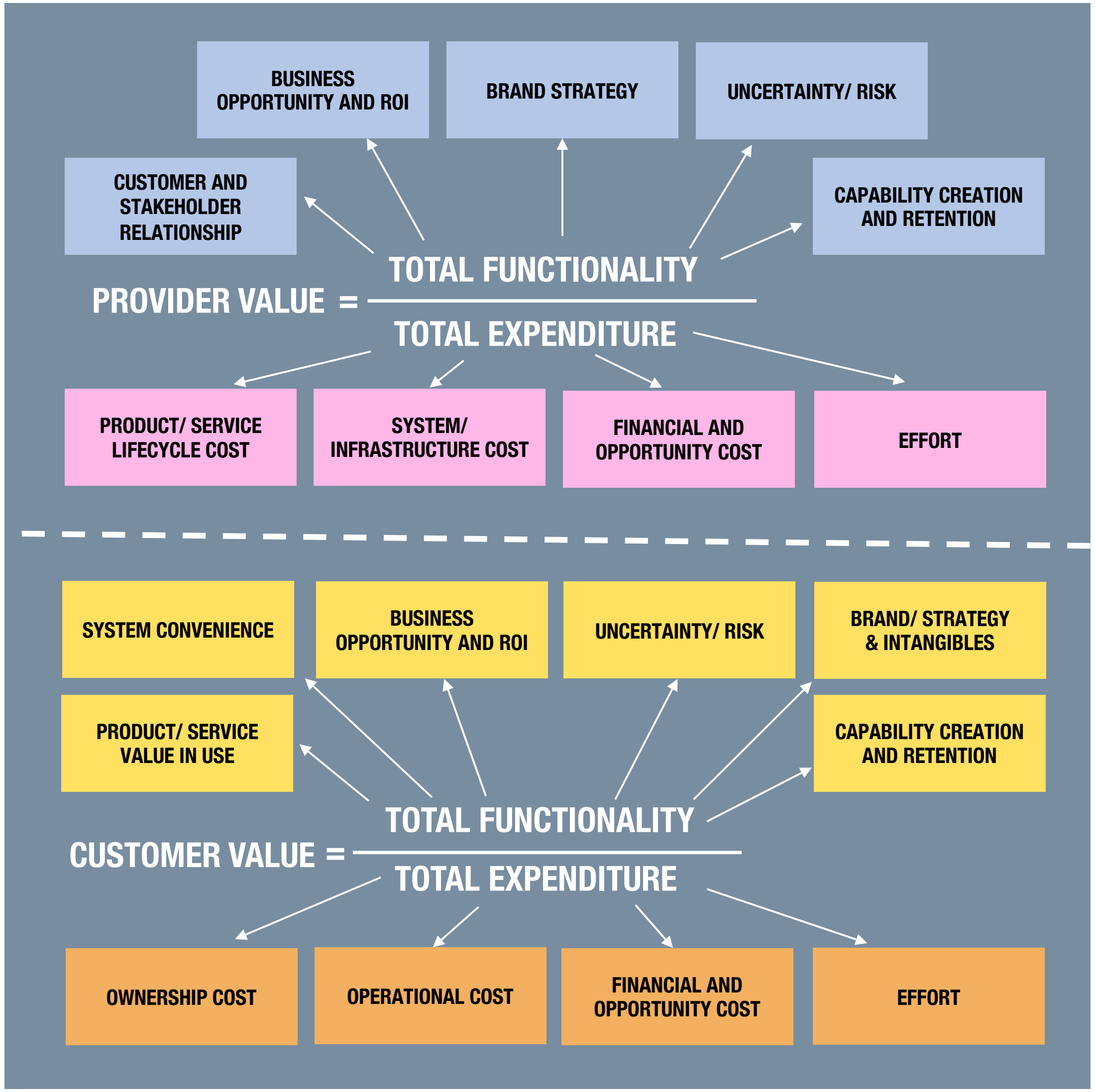
A Value Creation Strategy (VCS) is formalised as a list of linearly independent value criteria with associated rank-weights. It is extracted from the Voice of the Customer and need description and represents the 'standpoint' of customer value creation.

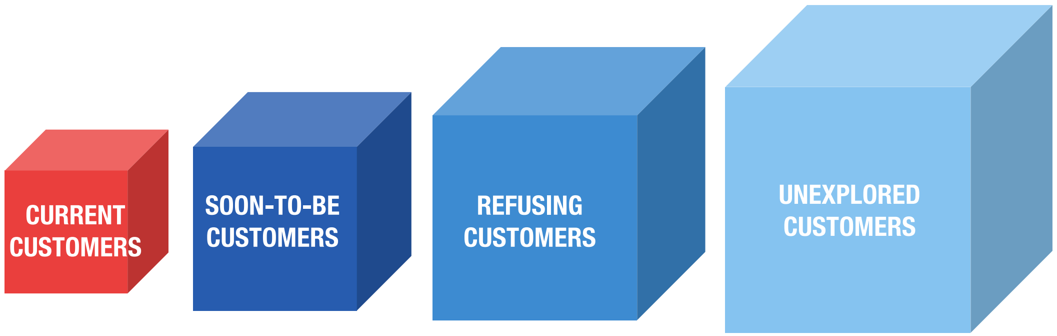
Task 1: The design team defines a list of value criteria in the VCS by considering customer and provider criteria separately, and further distinguishing between "gains" vs. "pains" (functionality vs. expenditures) – see framework on the right.

Task 2: Initially, a few criteria for customer and provider value might suffice in a very preliminary phase. Later in the process, when idea embryos become more detailed, up to 40 different criteria might be needed to perform the analysis with a higher level of granularity.

Task 3: The design team can vary the rank weights associated with the value criteria to represent the preferences of different customer tiers for the electrical hauler. For instance, sustainability-related aspects are emphasised to represent environmental conscious customers, while de-emphasising other aspects of value.

Task 4: The team can further tune the value criteria to reflect the provider strategy to mirror the way the organization makes business, its goals and values.





1.3. Customer Tier Analysis

A Customer Tier Analysis is a simple and intuitive tool that helps the design team in mapping how customers are likely to perceive new products and services.

Task 1: The design team is initially asked to describe the current customers in their business, and to provide indication about the size of this group.

Task 2: Later, the design team shall identify (and quantify in numbers) those groups of customers that, while purchasing minimal quantities today, are mentally noncustomers of the company. This groups are waiting to leave the industry as soon as the opportunity presents itself. However, if offered a leap in value, not only would they stay, but also their frequency of purchases would multiply, unlocking latent demand.

Task 3: The design team shall further identify those customer groups that are consciously refusing what the company has to offer. These are buyers who have seen the current offering as an option to fulfil their needs but have decided against buying-in. This group is typically larger that the soon-to-be one.

Task 4: Eventually, the team identifies a the third tier of noncustomers, which is the farthest from the market. They are noncustomers who have never considered the company's offering as an option. This is commonly the largest group.

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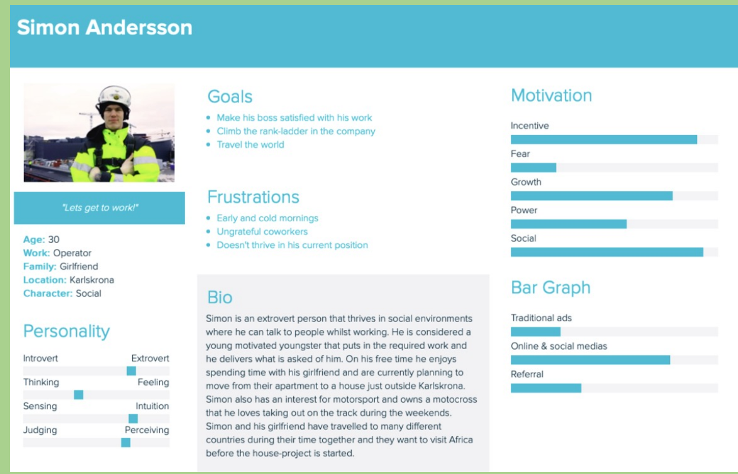

1.4. Personas

Personas are abstractions of groups of real consumers who share common characteristics and need. They are represented through a fictional individual and are synthesized from data collected from interviews with several users.

Task 1: Conducting Interviews with real users (e.g., the operator of a mining equipment) is a common method to create Personas. The design team must decide who to interview by listing the groups of people that might use the product/service. Trends are usually seen after talking to 10 or more users. Reviewing market research and surveys provide richer data and verification.

Task 2: The narrative of a persona starts with a description of the type of individual that the persona is, including information on likes and dislikes, demographics, occupation, and so forth (as well as a picture), to bring the persona to life.

Task 3: Here the design team shall describe in detail the persona's specific needs and personal goals in the context of the product/service being designed. This segment of the narrative helps to inform the resulting design decisions.

Try Out (with example)

At the following link you can find a template to generate your own Personas: LINK.

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"Ilities are desired properties of systems that often manifest themselves after a system has been put to its initial use"

De Weck OL, Roos D, Magee CL. Engineering systems: Meeting human needs in a complex technological world. MIT Press; 2011

1.5. Ilities

PSS offerings need to deliver the highest possible value for stakeholders and customers both under expected circumstances and in the presence of phenomena that disrupt their operation. Several specific abilities are relevant to consider when defining the value criteria of the VCS.

Value Robustness: the ability to provide value in the presence of an internal and/or external change in value scales.

Scalability: the ability to scale up (or down) the form (e.g. hardware) or the function of the products and systems.

Flexibility: the ability of a solution to be flexible in front of internal or external change agents.

Versatility: the ability to react to a change of the customer needs and expectations.

Win-win ability: the ability to maintain fruitful win-win situation even in case of changes in the environmental conditions.

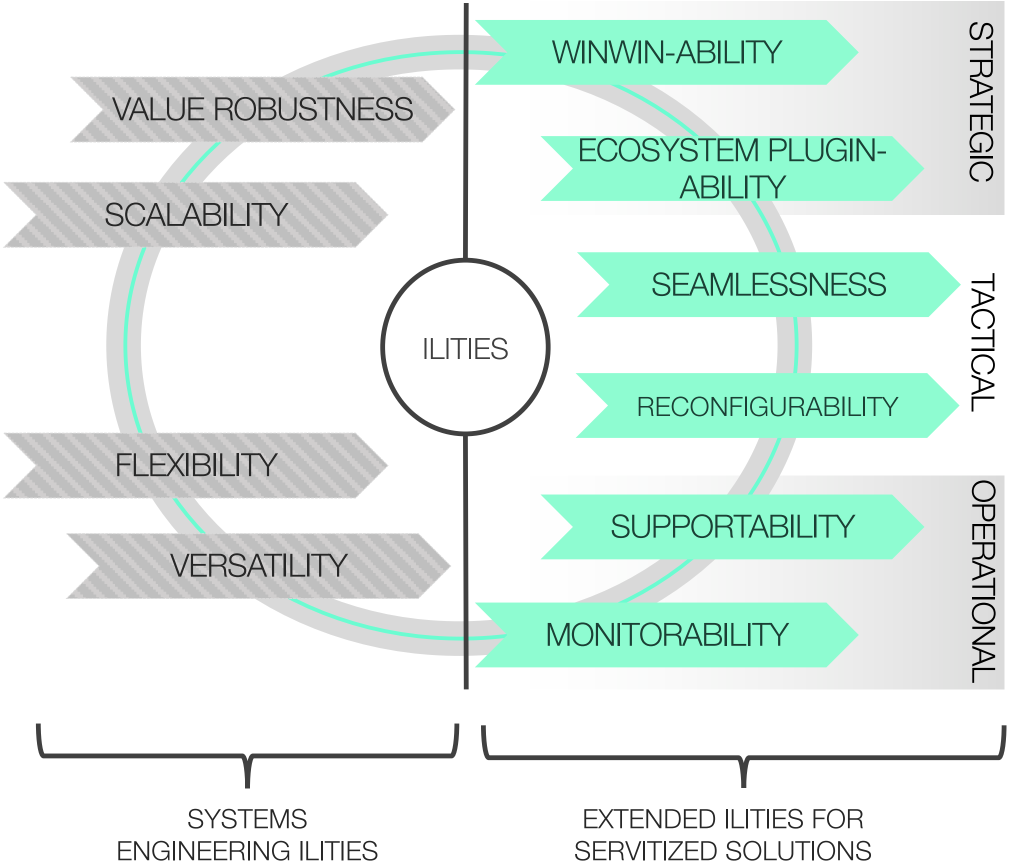
Ecosystem plugin-ability: the ability to allow suppliers to plug-in (or plug-out) new solution components as soon as a value opportunity appears.

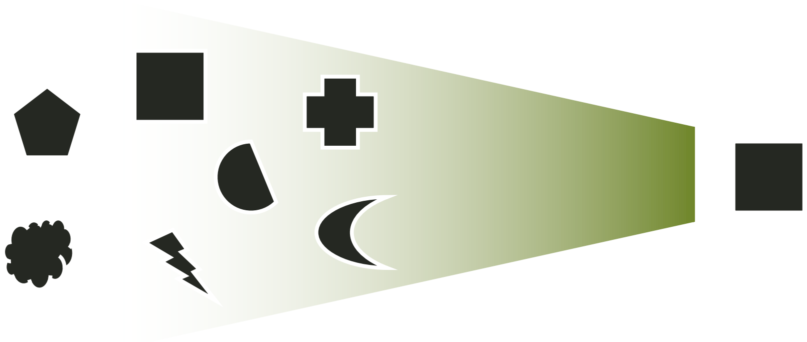
Seamlessness: the ability of the PSS to be seamlessly absorbed by the customer operational process, ensuring continuous value delivery.

Reconfigurability: the ability to reconfigure the network of actors to ensure flowless value delivery to customers.

Supportability: the ability of the service process below the 'line of sight' to support continuous value delivery.

Monitorability: the ability to monitor processes above and below the 'line of sight'.





STEP 2: SCREENING IDEAS FROM A VALUE PERSPECTIVE

What will be the outcome?

- A systematic, collaborative approach to support a preliminary, iterative screening of PSS embryos in a multidisciplinary setting.

Data-information required

- An initial list of design concepts presented in form of a short textual description and sketch.

People required

- The extended design team, including all functions having relevant knowledge about the solution.

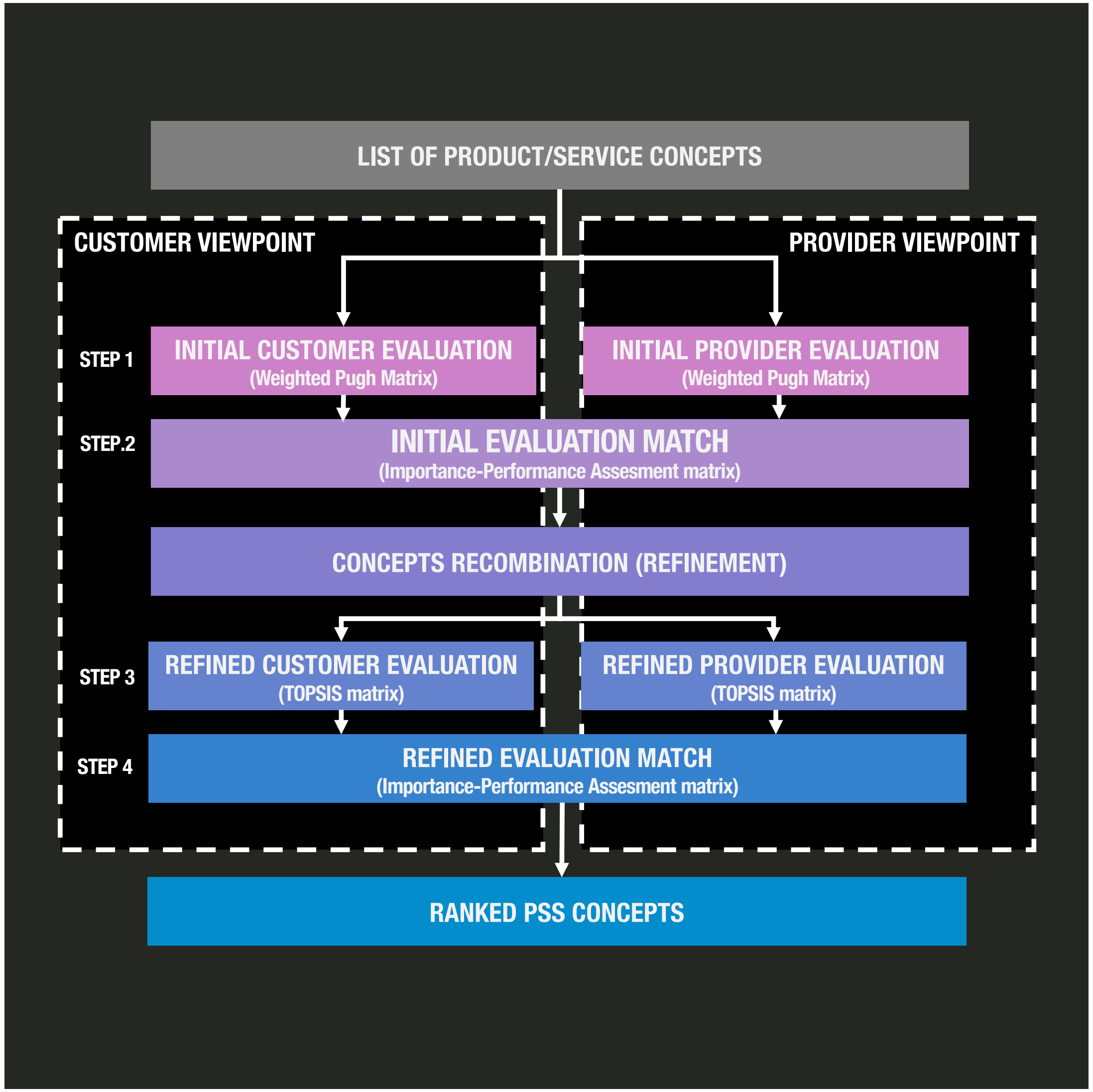
2.1 The EVA method

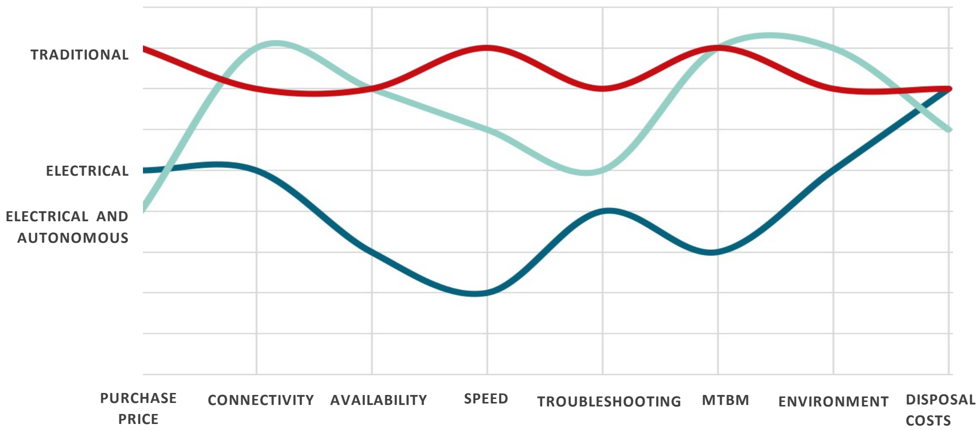
After defining the VCS, value models in form of multi-criteria decision making (MCDM) matrixes are proposed to support each individual in the cross-functional team in bringing along different criteria and points of view, which must be resolved through a process of mutual understanding and compromise.

These qualitative models are aimed at facilitating value negotiation during co-located focus groups in a workshop-like setting, involving participants from different organizational functions and (when possible) customers.

The modeling process kicks-off by requesting the workshop participants to generate a first list of design concepts, which are then compared based on multiple criteria with respect to an existing concept, called baseline

The results of the assessment along the list of criteria are then aggregated using the rank-weights defined in the Value Creation Strategy to obtain a score representing the value of a design concept.





2.2. The Value Strategy Canvas

The Value Strategy Canvas is a simple tool to benchmark design concepts and to provide a graphic depiction of how different solutions contribute to generate value.

Task 1: Initially the design team shall list the products/services they want to compare against a concept. In this example above, the design team benchmarks alternative technologies for an articulated hauler being part of an fully electrical mining site. There include traditional diesel machines, battery-driven ones and fully autonomous and fully electrical equipment.

Task 2: The value dimensions collected in the VCS are shortlisted and used to benchmark alternative product/service concept's for the new solution.

Task 3: The design team can rate each design proposal – for instance the 3 hauler technologies mentioned before - from 0-5 according to each attribute, preferably using customer survey data.

Task 4: The team can eventually create the canvas by combining the data into a graph. A higher score along the vertical axis means that the company offers buyer more, and hence invest more, in that factor.

Try Out (with example)

At the following link you can find a template to generate your own Value Strategy Canvas: LINK.

	CRIT. #1	CRIT. #2	CRIT. #3	CRIT. #4	....	CRIT. #N	WEIGHT
CRITERIA #1	1	3	9	1		1/9	18,5%
CRITERIA #2	N/A	1	3	1/3		1	6,3%
CRITERIA #3	N/A	N/A	1	1/9		1/3	3,9%
CRITERIA #4	N/A	N/A	N/A	1		1/9	15,3%
CRITERIA #5	N/A	N/A	N/A	N/A		1	7,9%
....							
CRITERIA #n	N/A	N/A	N/A	N/A		1	10,1%

2.3. The Analytical Hierarchical Process (AHP)

Not all the value criteria have the same importance when evaluating product concepts. The Analytical Hierarchical Process (AHP) is a useful technique to generate a weight for each value criterion in the VCS. AHP is based on the pairwise comparisons of the criteria. The higher the weight, the more important the corresponding criterion

Task 1: The design team collects all the relevant value criteria for the evaluation and forward them in a so called 'triangular matrix'

Task 2: The team shall chose a scale to compare pairs of criteria The 1-3-9 scale is the most commonly used in this respect.

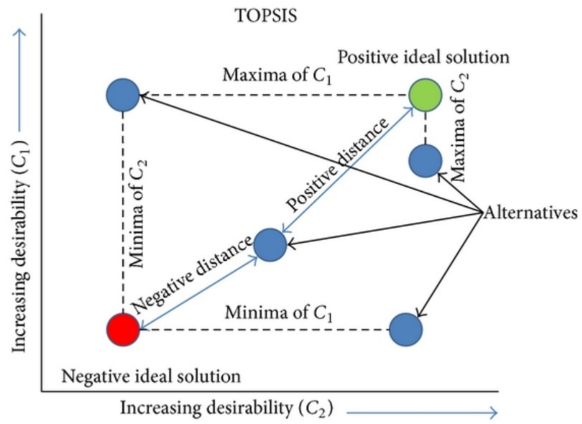
Task 3: In the matrix, each value criteria is compared against each other using a process of pairwise comparison. While 1 means that the two criteria has the same importance, 9 means that the criterion along the row is much more important that the one along the column, while 1/9 has the opposite meaning.

Task 4: The team calculates the Consistency Ratio (CR) for the AHP matrix, which represents the level to which the pairwise comparison is consistent across the AHP. A CR above 0,1 means that the matrix is inconsistent and shall be reviewed.

Try Out (with example)

At the following link you can find a template to generate your own Value Strategy Canvas: LINK.

VALUE CRITERIA	WEIGHT	BASELINE	CONCEPT 1	CONCEPT 2	CONCEPT 3
CRITERIA #1	%	0	+	+	0
CRITERIA #2	%	0	–	0	+
CRITERIA #3	%	0	–	0	+
CRITERIA #4	%	0	–	0	+
CRITERIA #5	%	0	0	–	+
….					
CRITERIA #n	%	0	0	–	+
		0	**-3**	**-1**	**+5**



2.4. The PUGH matrix

The Pugh matrix is the first step of the EVA method, and it is designed to accommodate concepts that are very heterogeneous in nature, spanning from pure products to pure services or concepts that are still immature.

Task 1: The design team lists a number of design concepts to be compared against a baseline. The list of value criteria defined in the VCS is further imported in the matrix.

Task 2: While the baseline scores are all set to 0, the remaining concepts under evaluation are assigned a "+", "-" or "0" score if they are, respectively, better, worse or equal to the baseline for each criterion.

Task 3: Once the matrix is completed, concepts are given a total score by summing up all "+", "-" or "0" obtained.

Task 4: The assessment through Pugh is repeated twice, firstly with a focus on the customer, then on the provider.

Noticeably, the primary purpose of Step 1 and of the Pugh matrix is to identify opportunities for improvement, recombination and refinement of the concepts step one could be performed iteratively until concepts features are well established and refined.

Try Out
At the following link you can find a template to generate your own Pugh matrix: LINK

2.5. The TOPSIS matrix

Once the concepts are improved and more detailed, they are forwarded to Step 2 of the EVA method.

Here, the evaluation is performed with more detail, expanding the set of evaluation criteria based and applying the TOPSIS technique. Also in this case the assessment is repeated to evaluate the value from a double perspective: customer and provider.

Task 1: Initially, each design team participant is asked to score a proposed PSS concept using a score from 0 (worst) to 5 (best) for each value dimension, and from 0 (best) to -5 (worst) for the cost criteria.

Task 2: TOPSIS applies a mathematical algorithm that measures the shortest distance from a positive ideal solution and the farthest distance from a negative-ideal solution.

Task 3: Each concept is eventually assigned a score from 0 to 1, where 1 corresponds to the ideal solution and 0 corresponds to the worst solution.

Task 4: The scores obtained for all the concepts evaluated in TOPSIS are displayed along a 2 dimensional diagram (Called Importance-Performance matrix or IPA), with provider value on the x axis and customer value on the Y axis. This

Try Out
At the following link you can find a template to generate your own TOPSIS matrix: LINK

"We adopt a set-based approach to decide which concepts to develop. This means that we do not choose the best concept, rather ***we progressively exclude the worst ones and then iterate****.*

As soon as a concept shows that is not feasible, or it does not meet the criteria, ***we eliminate it*** *and continue to evaluate the remaining in more detail, so to finally identify the subset of concepts that meet the criteria targets"*

Design process leader, VCE

Example

In this example, the design team worked with the development of 150 different configurations of the autonomous hauler.

Task 1: Each stakeholder ranked the value criteria for the hauler independently (using a scale form -5 to +5), based on their level of importance. The complete list of value criteria was composed of 42 items for customer value and 43 for provider value

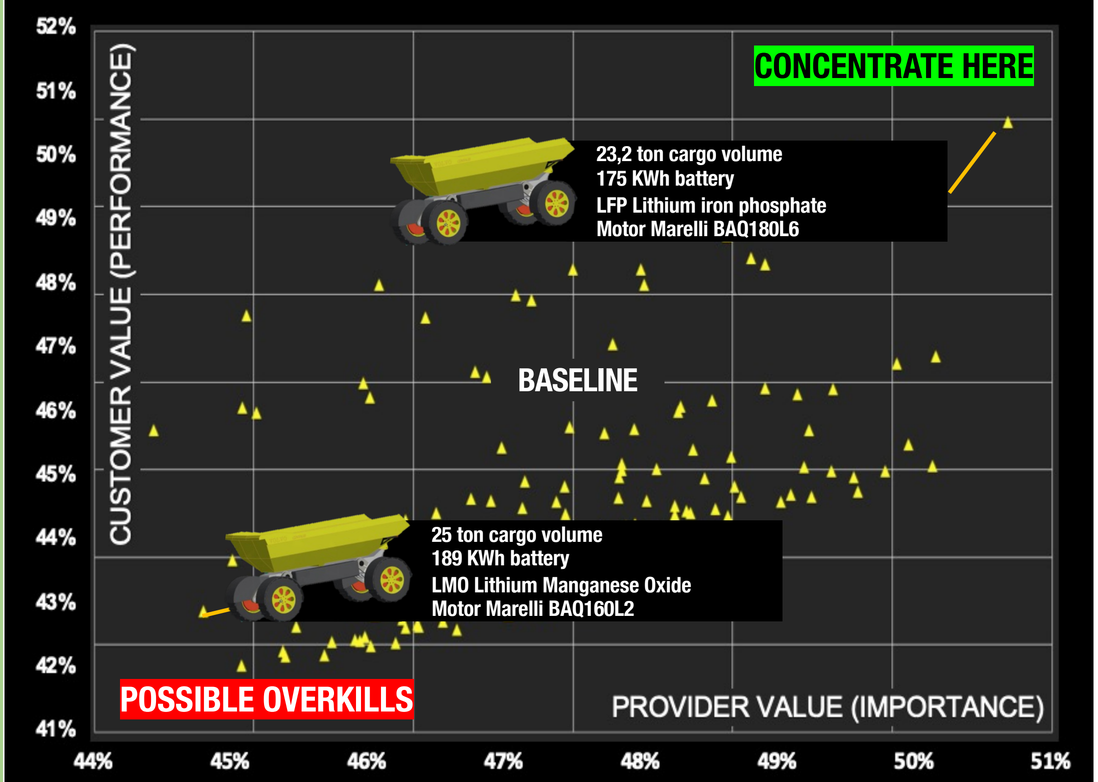
Task 2: Each stakeholder ranked all the available design alternatives independently (using a scale form -5 to +5) based on the level to which a design satisfy the criteria.

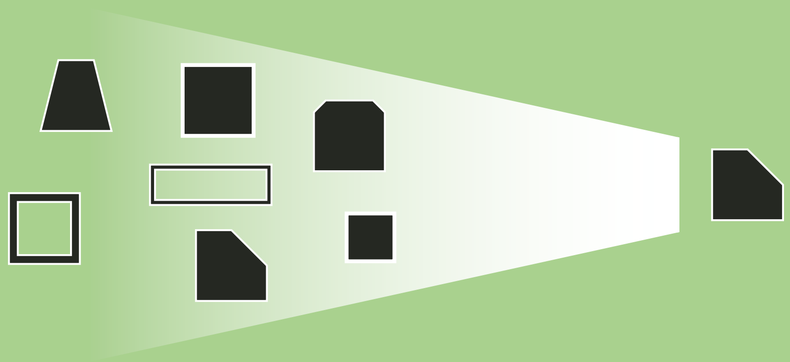
Task 3: Scores were collected in the TOPSIS matrix and normalized. Then, the positive and negative ideal solution were calculated on the basis of the gathered inputs.

Task 4: An ideality score from 0 to 1 was produced as output of the TOPSIS matrix to facilitate the down selection of different concepts.

Task 5: The Importance-Performance Analysis (IPA) diagram was used to improve the visualization of the results. Provider value was displayed along the x-axis together with Customer value along the y-axis.

The IPA diagram allowed to identify value-adding solutions to be developed further, together with possible overkills to be eliminated from further investigations.





STEP 3: ASSESSING THE VALUE OF DESIGN CONFIGURATIONS

What will be the outcome?

- A detailed assessment of the value of several design configurations for a design concept.

Data-information required

- A list of the main engineering characteristics for the concepts, including specific values and boundaries, together with the VCS information defined above.

People required

- Product development process owners, engineers and designers.

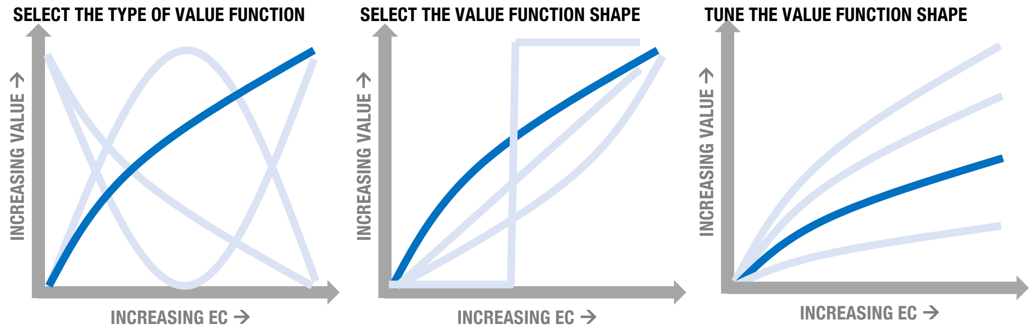
3.1 The issue of non linear value functions

Increased resolution in the solution description opens up room for more sophisticated modeling approaches, to better capture the rationale behind design concept assessment and to document richer lessons learned that can be exploited in future projects.

A major aspect here is that the degree of need fulfilment for a new solution is not linear but reflects the diminishing returns that are typical of utility curves.

3.2. The EVOKE approach

EVOKE is built on the COncept Design Analysis (CODA) method and exploits non-linear merit functions - Maximize (Max), Minimize (Min), Optimize (Opt) and Avoid (Avo) - to calculate the value of new solutions.



Task 1: The design team identifies a promising design concept from the results of the previous step and shortlists a set of relevant Engineering Characteristics (EC) for the solution. These are similar to requirements (being formulated as criterium + value) and distinguish between alternative configurations of the proposed design concept.

Task 2: The EC are mapped against the list of value criteria listed in the VCS. The mapping is performed first by:

- Identifying the strength of the relationship, which is represented by numerical coefficients (0-0,1-0,3-0,9).
- Identifying the type of value function characterizing the relationship (e.g., Max, Min, Opt, Avo).
- Identifying the shape of the value function (e.g., linear, concave, convex, step).
- Defining tolerances and neutral points to tune the overall shape of the function.

Task 3: The CODA algorithm further calculates the value of each design configuration along each criteria, eventually merging these results to produce a single design merit score from 0 (lowest value) to 100% (highest value).

3.3. Managing knowledge in the EVOKE model

An Issue Based Information System (IBIS) model is used in the VDD methodology to capture knowledge related to the relationships between the Engineering Characteristics of a design and the value criteria.

An IBIS map takes the shape of a graphical network that integrates many problems, solutions, and points of view and shows the deep structure of an issue.

Step 1: In order to build an IBIS map, the design team must first identify a relevant question to be answered.

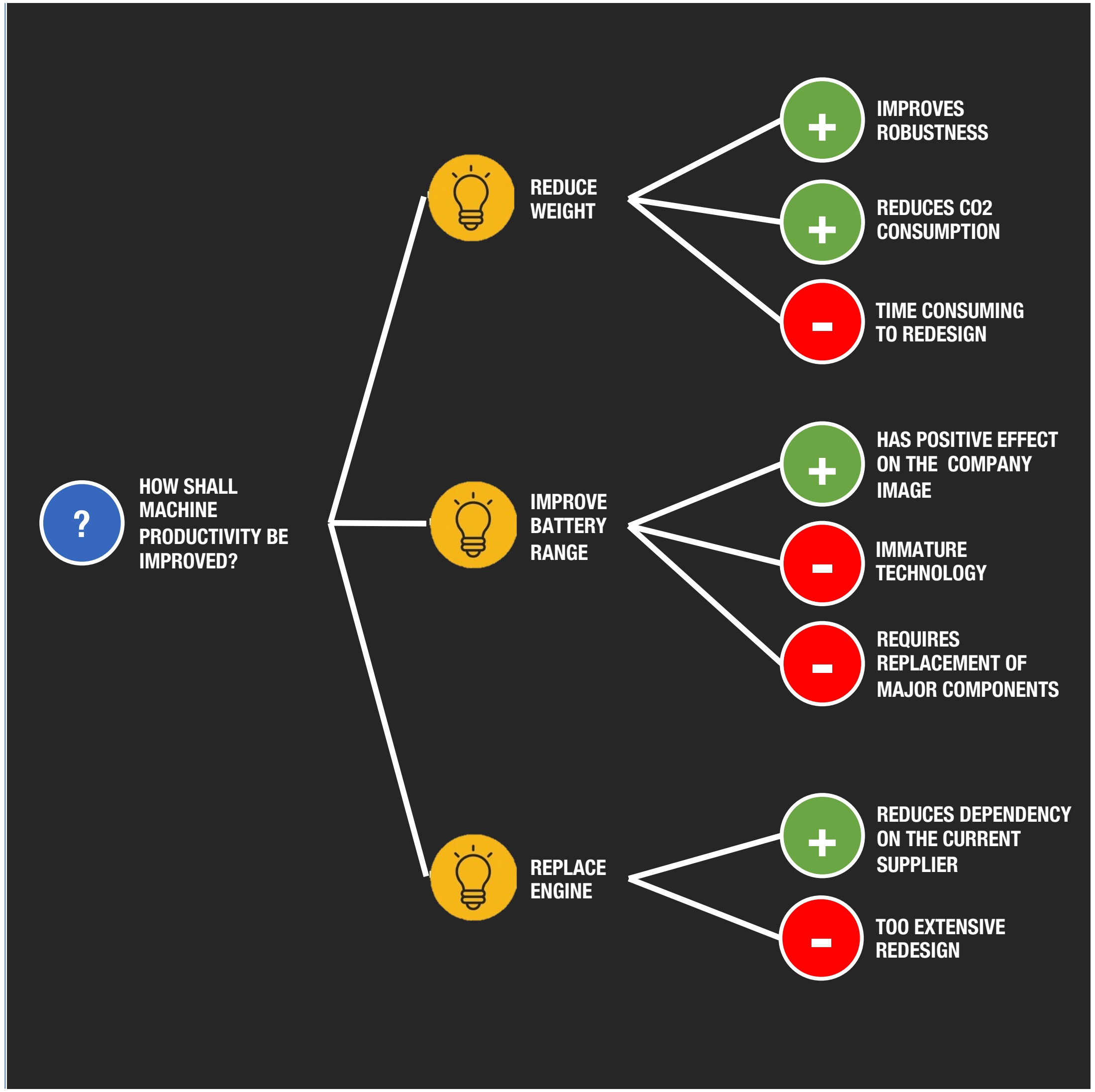
Step 2: The design team shall then identify and formalise alternative positions (possible answers) related to the initial question.

Step 3: Everybody in the extended cross-functional team is then invited to provide arguments which support (or reject) a given position (or another argument).

Step 4: In the course of the treatment of issues, new issues come up which are treated likewise.

In the autonomous hauler example, IBIS has been used to map the relationship between a value driver (e.g., 'Productivity') is expected to be influenced by varying the engineering characteristics of an equipment, such as the machine overall weight, its battery range or engine type.

The map is collaboratively built by all those individuals having knowledge in the organization, and further used to define the value functions, boundary conditions and correlations in the EVOKE matrix.



Example

In the example, the EVOKE model was applied to support the detailed value assessment of a set of design configurations for the autonomous hauler based on the design concept identified in the TOPSIS matrix in the previous step.

Task 1: Design configurations were described by a list of 17 EC, that captured geometrical dimensions for the most critical hardware sub-systems, as well as performance data (battery capacity, charging time and more) and life cycle data.

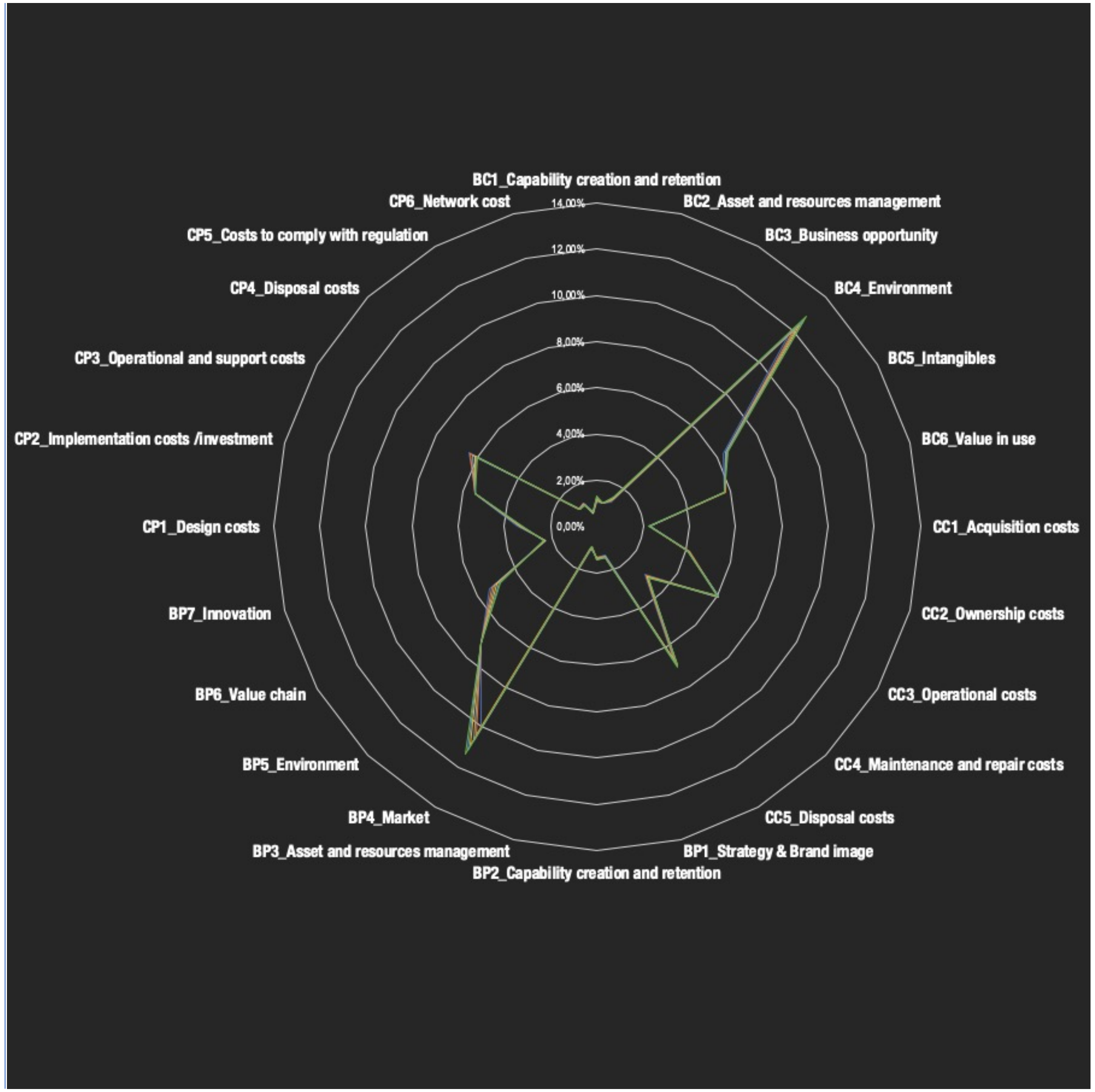
Task 2: An IBIS model was implemented to capture knowledge related to the upper and lower bounds of the selected EC, and to their relationship with the value criteria. Pro/con arguments in the tree were further tagged with a model maturity score (see step 6).

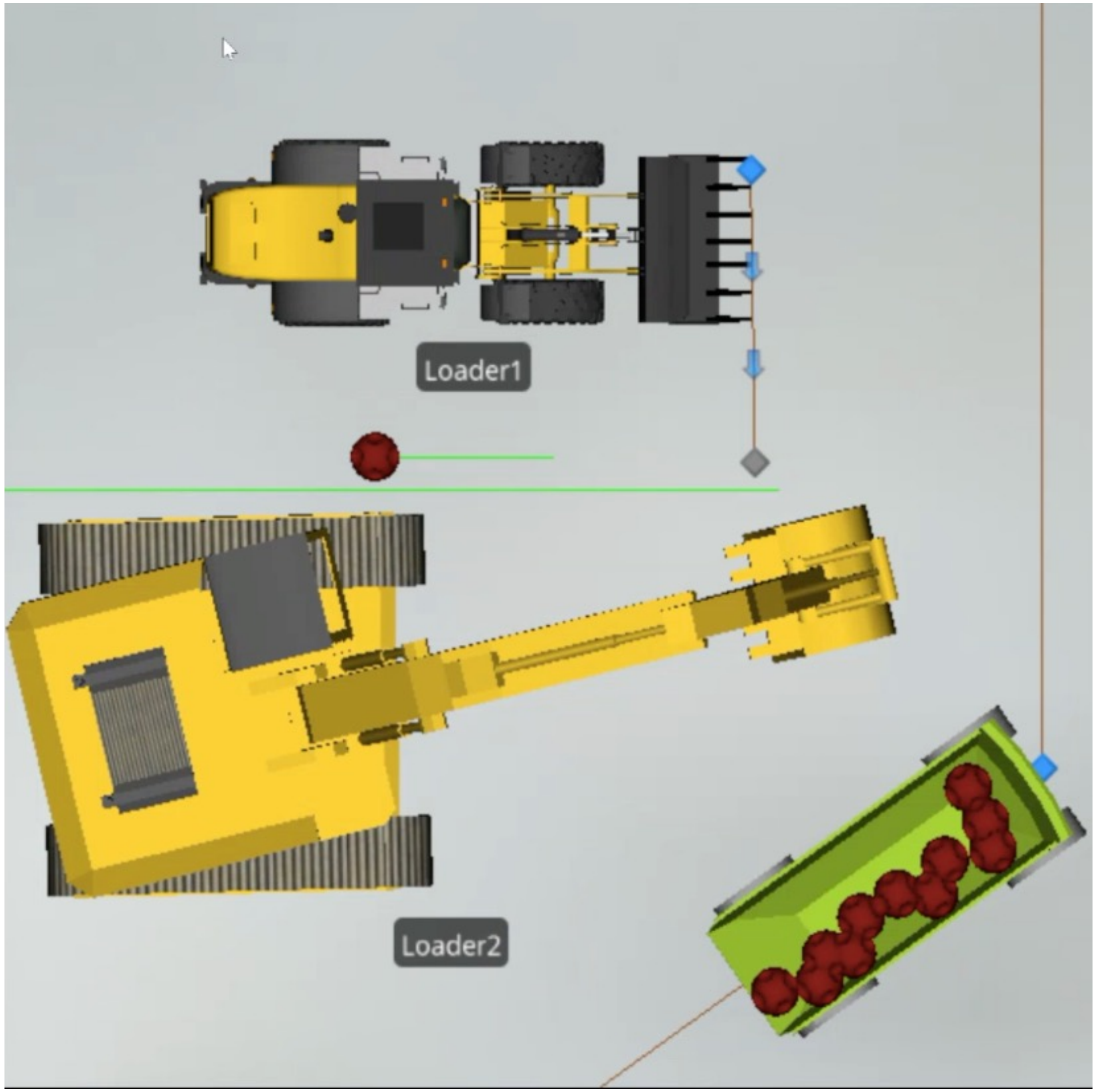
Task 3: Value criteria and EC were mapped in the CODA model following the procedure illustrated in the previous section.

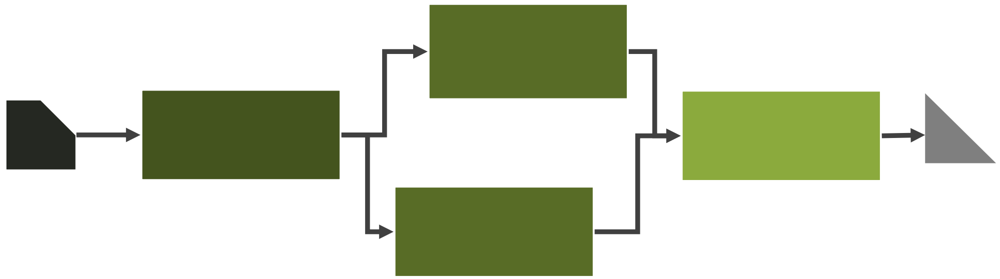
Task 4: The results of the CODA for each value criteria were aggregated and a single design merit score was derived for each design configuration.

Task 5: The final results from the EVOKE assessment for all considered design configurations were displayed in a spider plot for benchmarking purposes.

Task 6: The design configuration featuring the highest design merit (the highest value score) was selected for further development.







STEP 4: SIMULATING FUTURE SCENARIOS

What will be the outcome?

- Performance-related information for each design concept.

Data-information required

- A process representation for how the PSS is manufactured, operated, maintained, repaired, decommissioned and more.

People required

- Engineers, designers, simulation expert, product specialist, field technicians.

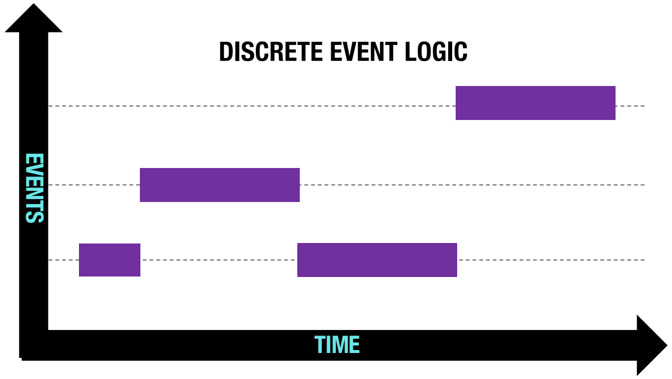
4.1 Generating hardware configurations

In order to calculate the operational performances of a concept, it is necessary first to create a parametric 3D CAD representation of the product. From this it is possible to generate a number of alternative design configurations using Design of Experiment (DoE) approach.

After selecting a subset of variables to be varied in the study, as well as the number of design configurations to be generated, the team can choose a suitable statistical method for generating the experimental plan.

Each instance is inputted in the 3D CAD environment to automatically generate a geometrical model of the hardware. Each of these models renders a number of physical properties, such as dimensions for all parts, weight data, centers of gravity and more.

These are inferred by the 3D representation considering the actual displacements, loads and interface requirements. This information is used to further calculate stresses and deformations for critical components in the system.



4.2 Forecasting the behaviour of the PSS hardware

Task 1: The design team develops simulation models using a discrete event logic. These Discrete Event Simulation (DES) models mirror the way the solution will be operated, maintained and decommissioned or recycled along the lifecycle

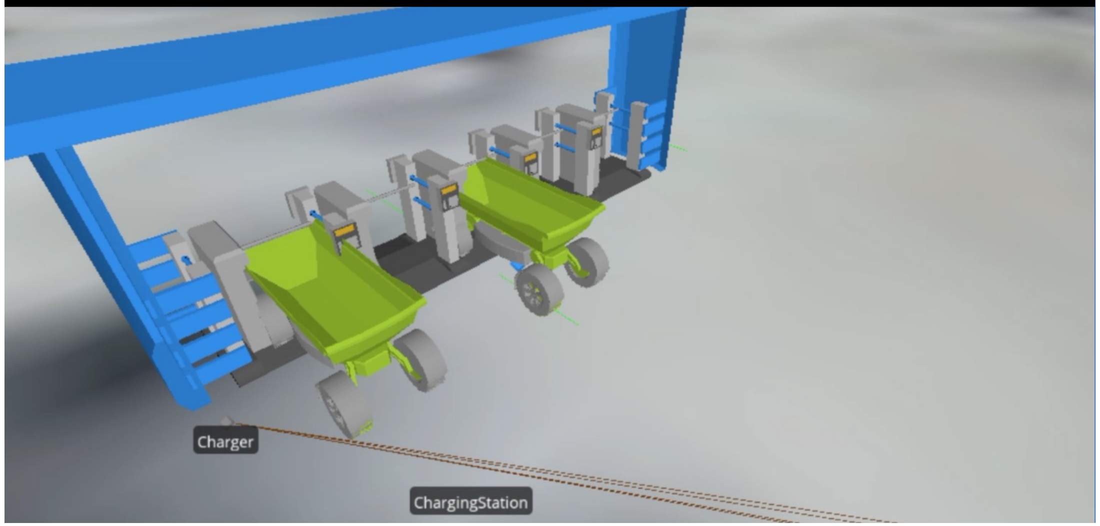
Task 2: The geometrical, physical and functional characteristics obtained in the CAD environment for each configuration are inputted in ad-hoc DES models to calculate the in-usage performances and other critical process metrics.

Task 3: The DES models are checked for consistency and iteratively refined during the development process. It is possible at this step to create several simulations to estimate manufacturability, serviceability, maintainability, upgradeability, recyclability and more.

Task 4: The simulation is used as basis to setup and run experiments with different hardware configurations, to identify trends and features of the machine that improve efficiency, quality and reduce cost in the process.

Try Out

Guidelines and instructions on how to create simple DES models, and how to configure experiments, can be found here: LINK



Example

The process was applied to simulate the value of alternative configurations of the autonomous hauler concept in different operational scenarios.

A **DES model** was constructed to replicate the operations of several prototypical mining sites, considering loading/ crushing operations, transportation and charging.

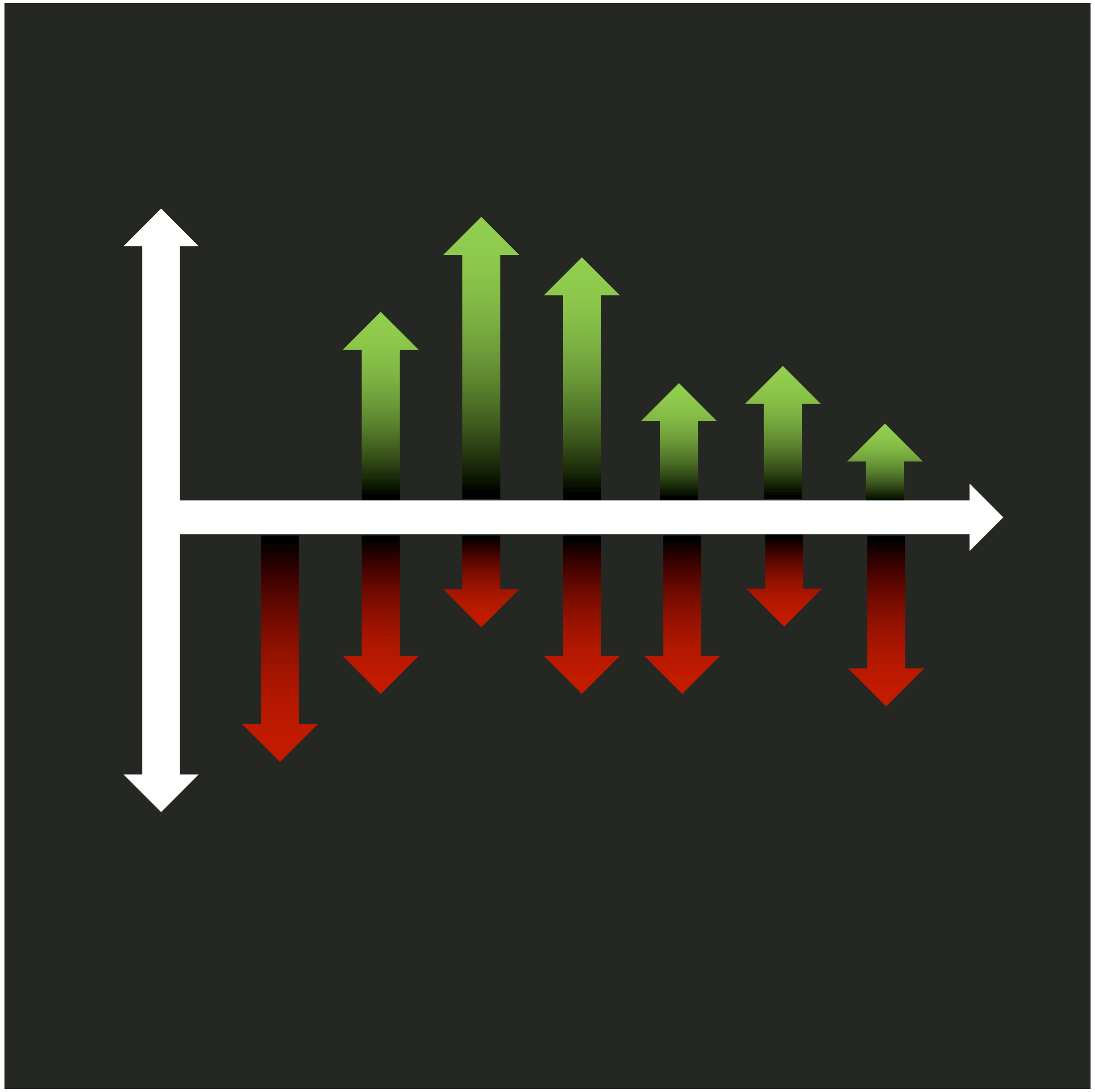
A fleet of machines, with varying range, cargo size and charging time was tested within the scenarios to obtain information on cycle time, productivity, availability and more.

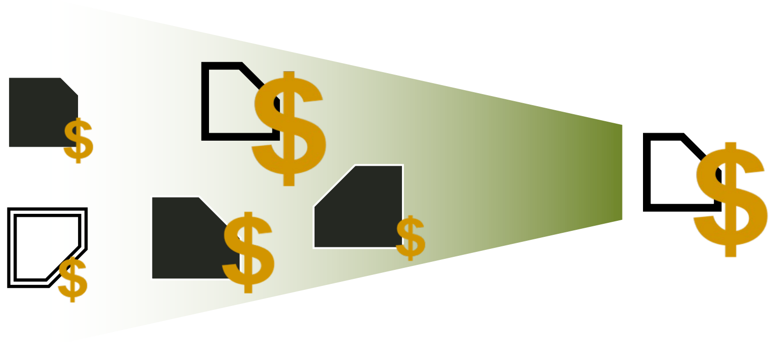
The simulation model is shaped to represent a prototypical mining cycle. After charging the batteries at the parking hub, the equipment moves to the first station where it is loaded by a wheel loader.

Form here, the equipment delivers its cargo either to Crusher 1 or Crusher 2, which are working in parallel.

The hauler is later loaded again with crushed rock, which are further deliver to a third crushing station. At the end of this task, the machine goes back to charging, and the cycle repeats.

The DES simulation is used here to calculate the battery state of charge for different hauler concepts, at varying cargo capacity, battery size, and process conditions.





STEP 5: CALCULATING THE MONETARY VALUE

What will be the outcome?

- A monetary score and other financial metrics indicating the revenue and cost linked to a design configuration, n considering its entire lifecycle

Data-information required

- Cost data, discount rates, lifespan for the solution, time period for the investment.

People required

- Engineers, designers, product specialist, manager, business analyst.

5.1. Quantitative value models

Monetary units are the most convenient, practical and universally understood metrics for value assessment in product development and engineering design.

Quantitative value models are introduced in a later stage of the PSS design process, when early concepts have been detailed and more precise information on the cost items, as well on the customer operational process, are available.

Monetary value models aims at assessing the long-term profitability of a solution for both customers and provider. Noticeably, they force decision makers to consider not only cost but also all those revenue items that characterize the life of a product or service, together with other system-of-systems effects that can influence long-term profitability.

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COST MODEL	ACQUISITION COST	OPERATING COST	CHANGE COST
HARDWARE	OBVIOUS COST!	OBVIOUS COST!	HIDDEN COST
SOFTWARE	OBVIOUS COST!	OBVIOUS COST!	HIDDEN COST
PERSONNEL	HIDDEN COST	HIDDEN COST	HIDDEN COST
CONSUMABLES	HIDDEN COST	HIDDEN COST	HIDDEN COST
FACILITIES	HIDDEN COST	HIDDEN COST	HIDDEN COST

5.2. Total Cost of Ownership

Total Cost of Ownership (TCO) is an analysis that places a single value on the complete lifecycle of a capital purchase, including every phase of ownership, from acquisition to maintenance, from training to decommissioning, recycling.

Task 1: The design team shall first define the lifespan of the solution. Among the many different methods, Economic life (the number of years for which the asset returns more value to owners than it costs to operate) and Service life (the number of years the asset is actually in service) are the most common to define the lifespan.

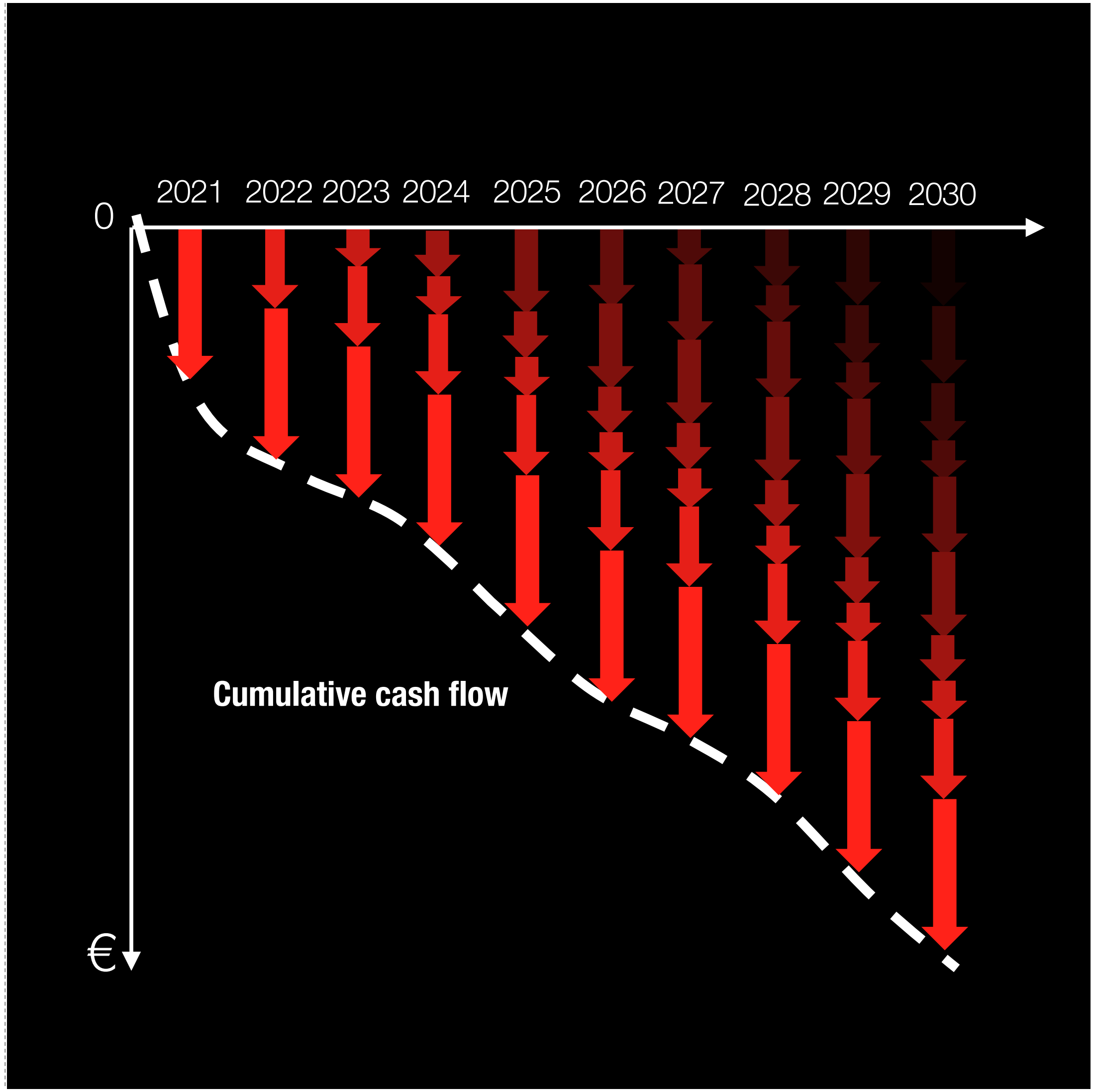
Task 2: The design team shall list all relevant categories of cost, paying attention to capture the most as well as the least obvious ones. The latter are hidden/ necessary/ large enough expenditures related to the decision to own something that are easy to overlook or omit from the concept down-selection task.

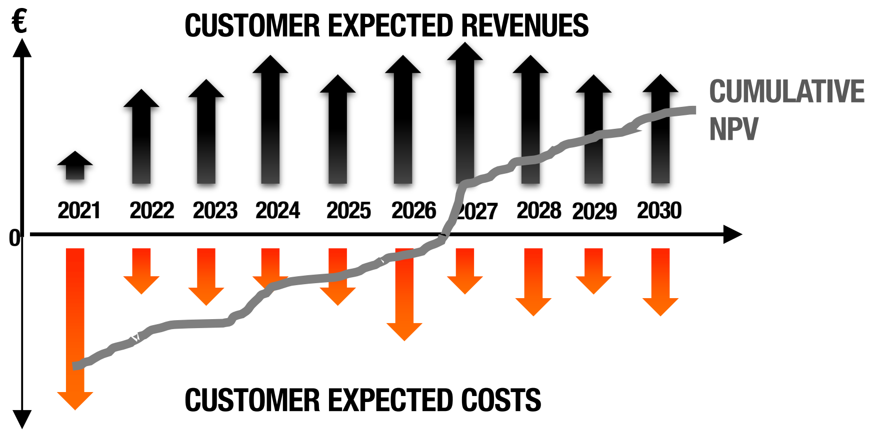
Task 3: The analysis continues by developing a model, designed especially to support decision-maker needs, covering all relevant cost items for the solution.

Task 4: The design team shall then estimate the cash flow for each solution. The cumulative cash flow can be used to benchmark a design concept against a given baseline, or against other proposed solutions.

Try Out

At the following link you can find a template to calculate your own TCO matrix: LINK.





5.3. Net Present Value analysis
NPV considers discounted expected profit (or Net Present Value) as the main objective of decision making by a risk-neutral firm. Value is calculated by forecasting/assessing (from a monetary point of view, using appropriate models) the ability of a design concept to generate positive revenue for our customer, then subtracting the costs for our customer along the lifetime of the provided solution.

Task 1: The design team shall first define the lifespan of the solution.

Task 2: Then it shall also define 3 reference scenarios for the analysis: the base case (all things proceed normally), the worst case (least favorable conditions) and the best case (most favorable conditions).

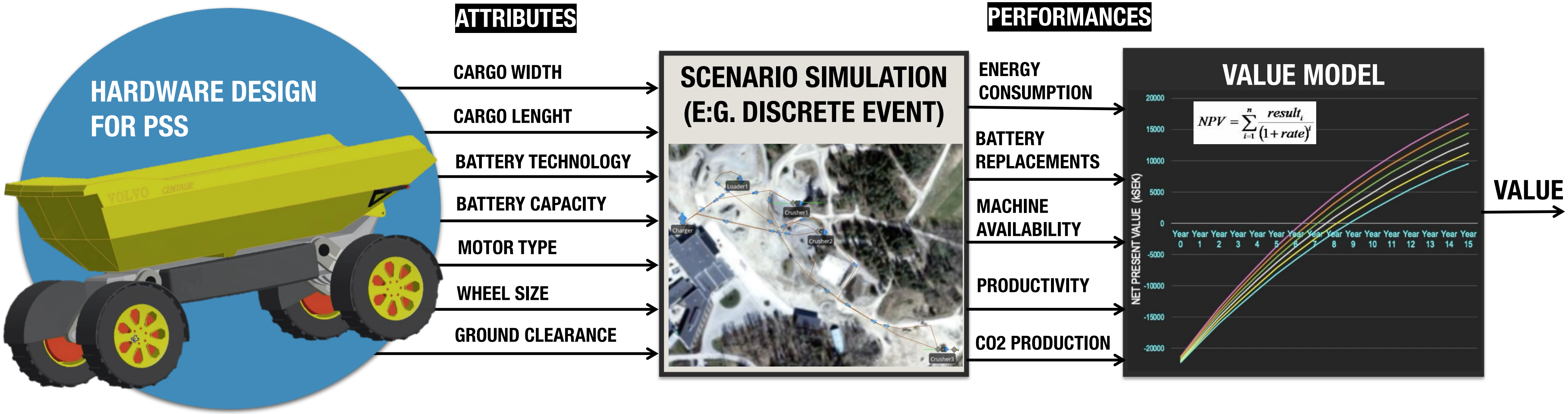
Task 3: A deterministic approach is applied to calculate revenues and cost in the 3 scenarios, using discrete values assigned to each parameter and ignoring uncertainty.

Task 4: A probabilistic approach can be further applied to improve the resolution of the results. Here the revenue and cost parameters are associated to a probability distribution. DES models with random functions typically support this step.

Task 5: The design team applies statistical methods such as MonteCarlo simulation to figure out the average outcome of a scenario.

Try Out
At the following link you can find a template to calculate your own NPV matrix: LINK.

	NORMAL SCENARIO	BEST CASE SCENARIO	WORST CASE SCENARIO
SALE PRICE		+10%	-15%
MANUFACTURING COST		-20%	+15%
TRANSPORTATION COST		-5%	+20%
NUMBER OF CUSTOMERS		+15%	-5%
TRAINING COST		-10%	+30%
DECOMISSIONING COST		-5%	+25%
DISCOUNT RATE		-2%	+5%
FAILURE FREQUENCY		-10%	+20%



Example

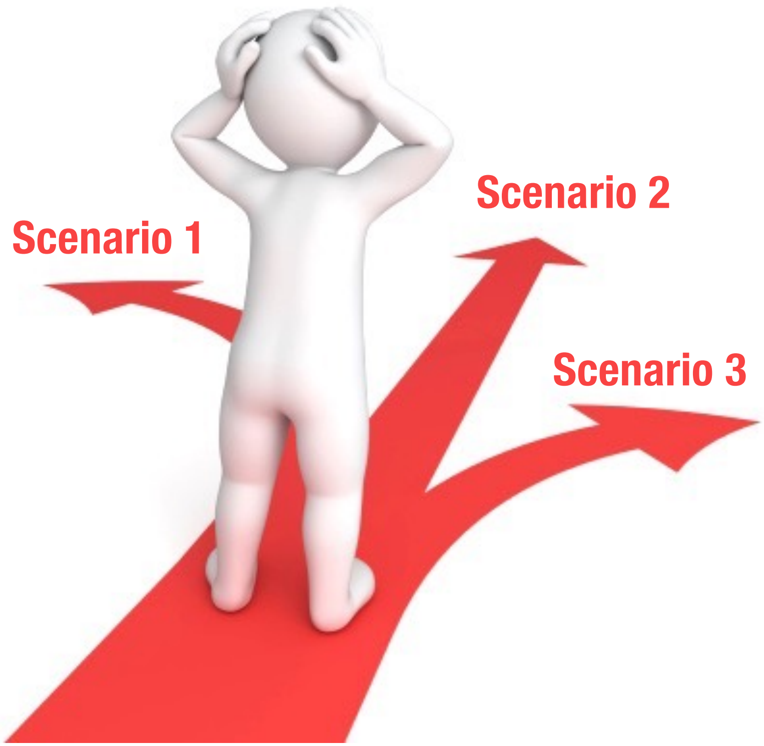
The results of the DES simulations were used to populate cost and revenue models for the autonomous hauler

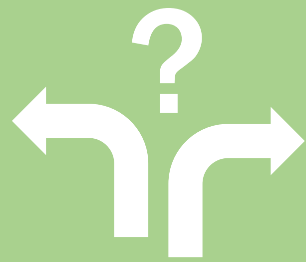
Simulation data were imported into the NPV model to assess the monetary value of the machine in a 15-year time period. Cost and revenue areas were shortlisted, distinguishing between items considered to be priorities, negligible or not assessable when developing the cost engineering approach.

In the process, the design team was able to switch between each scenario, modify the input parameters, and fine-tune both the cost and revenue items.

Several design configurations for the product can eventually be benchmarked in terms of cumulative revenue vs. cost output, payback period, return on investment and break-even

Eventually, the modelling results were used to identify the most valuable combination of hardware features in alternative product and service configurations.





STEP 6: ADDRESSING UNCERTAINTY IN THE PROCESS

What will be the outcome?

- An increased awareness of how much the results of the value modelling activities in the different steps can be trusted.

Data-information required

- Scenario data, information about data sources and competences involved in the development of the models

People required

- Possibly the extended cross-functional team.

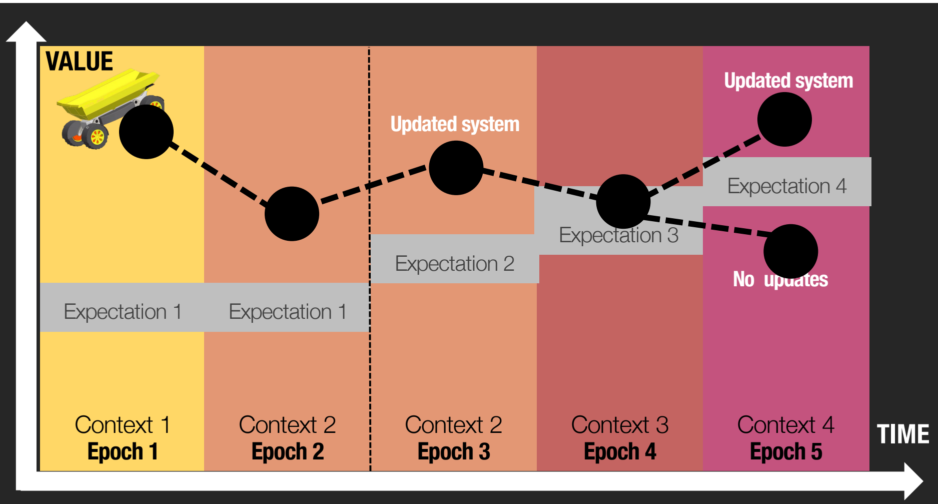
6.1 Strategies for uncertainty management

The outcome of the VDD process at each stage are strongly influenced by the uncertainty and ambiguity that dominates early stage design activities.

Two strategies have emerged in order to mitigate the risk associated to sub-optimal decisions at each step of the process.

On the one hand, the outcomes of the value modelling activities can be made more relevant to the design team by promoting the systematic exploration of feasible solutions in different future scenarios. The **Epoch-Era analysis** approach is used then to explore how value creation is affected by changing environmental conditions and customer preferences.

On the other end, the concept of **model maturity** has often emerged from the discussion with the research partners, being explained as a framework where to grow knowledge about the knowledge in a way to achieve a better understanding of what early stage uncertainties, ambiguities, and assumptions involve.



6.2. Epoch-Era analysis

Epoch-Era Analysis (EEA) helps the design team in evaluating the value robustness of design concepts. EEA provides insight into when in the evolution of a system a new product/service may need to be added, and when investments should be made in new technologies.

Task 1: The design team define different contexts for the application (e.g., for the autonomous hauler) and place them along a timeline. Changes in contexts might be related to new regulations taking place and other external factors

Task 2: The team then maps the changes in customer expectation for a given value aspect along the timeline. Noticeably, expectations might vary even if the context remain the same, and vice versa.

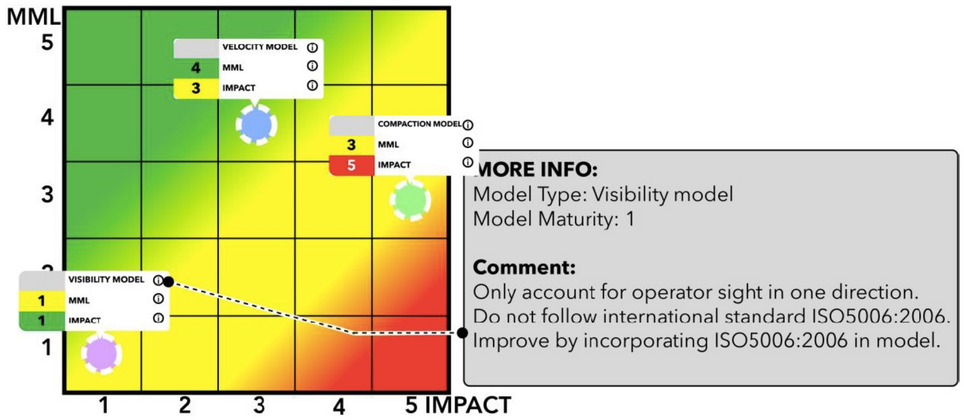
Task 3: The combinations of different contexts and expectations generates so called Epochs, and the design team shall now map how product/services provides value across them.

Task 4: Value provision over time is mapped across the Epochs, considering that obsolescence and the introduction of better competitive solutions tend to reduce value over time

Task 5: The design team uses the Epoch-Era diagram to plan for the introduction of major updates in hardware, software and service.

Try Out

At the following link you can find a template to calculate your own NPV matrix: LINK.



6.3. Model Maturity

Model Maturity is a support tool to improve the confidence and validity of the value models. In a nutshell it is used to communicate the uncertainties from the modelling and simulation work to relevant stakeholders

Task 1: The design team prepares the model maturity diagram. This is composed of 2 dimensions, a model maturity level (indicating the distance between the current value of maturity and the ideal certainty level to be expected from the model) and an impact score (defined as the effect the model has on the framing of a question of the development activity)

Task 2: The design team selects the specific model to be evaluated, and prepares a scale from 1 to 5, where 1 indicates low maturity and low impact, while 5 represents high maturity and high impact.

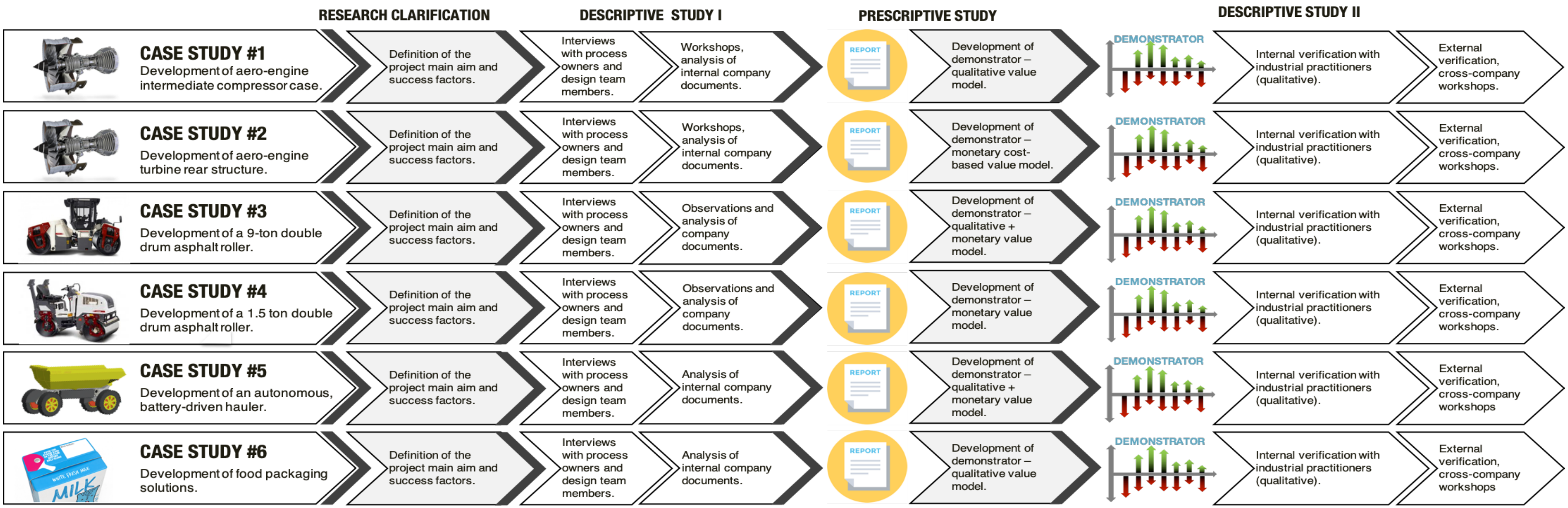
Task 3: The model is scored from 1 to 5 and comments are added to indicate the reason for a score to be low vs. high.

Task 4: The results from the assessment are visualised as dot in a color-coded diagram.

Task 5: The design team can further investigate to reveal additional rationale and suggestions for how to improve maturity of the models for PSS decision making.

Try Out

At the following link you can find a template to play with the Model Maturity concept : LINK.



RESEARCH APPROACH

The **Design Research Methodology** was used as the main reference for the development of the VDD process. The research is further based on a multiple case study approach. A total of six cases were selected to gather empirical data and draw cross-case conclusions.

The first two cases were conducted in collaboration with a design-make supplier to major aero-engine manufacturers, the third and fourth cases with a multinational engineering manufacturer of mobile compactors for road surfaces. The fifth case involved a world-leading total-solution provider in the construction sector, and the sixth case a multinational company in the food packaging sector.

The selection of cases follows a logic of 'literal replication', which is that of finding similar results in different contexts to provide compelling arguments for the initial proposition.

Noticeably, all companies are active in the business-to-business sector and are familiar with the notion of PSS as part of their portfolio. They have experience with cross-functional design teams and have grown lessons learned on the need to facilitate a participatory process in the design. At the same time, their business is facing rapid transformations, largely driven by the same macro trends: digitalization, connectivity, artificial intelligence, and resource scarcity.

WHAT NOW?

At the end of the Value-Driven design process, the design team is ready to deliberate with confidence about which solution concepts shall be brought forward to the detailed design stage.

Here the design will be engineered with more precision, yet with a good awareness about how and why the selected proposal is considered to be the most suitable one for the chosen customers and markets.

It is also very important at this stage to collect reflections, lessons learned and experiences about the application of the VDD approach, to improve the process and fine tune methods and tools before the next project.

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