Product Journey Mapping
a design method to shift towards the circular economy

Master thesis
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April 2022

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April 2022

Executive summary

At this time, our linear economy urgently needs to transform towards a circular, less wasteful system to restrain the global environmental footprint of the products we use (Hans Bruyninckx, 2016). To move toward a circular economy, Bocken et al. (2015) identify three approaches: slowing resource loops, closing resource loops, and narrowing resource loops. Firstly, slowing resource loops extends a product's lifecycle through maintenance and repair, thereby extending the product's utilization period. Secondly, closing resource loops, through, for example, recycling, closes the loop between post-use and production, resulting in a circular flow of resources. Thirdly, narrowing resource loops refers to using fewer resources per product. To facilitate this transformation towards a circular economy, industrial designers need a complete and systematic way to map a product's lifecycle, a product journey map (PJM). Therefore, this graduation project developed a PJM that can help industrial designers identify opportunities to slow down and/or narrow down and/or close resource loops by systematically mapping the products' lifecycles.

The Product Journey Map was developed through an iterative process, preceded by research on design methodologies (Daalhuizen, 2021) and existing mapping methodologies such as the Customer Journey Map and Service Blueprint. By synthesizing the research on design- and existing mapping methodologies, I developed a vision of the Product Journey Map, which I explored through four concepts. The concepts took inspiration from the work of Bocken (2016) and Evans & Yung (2019) on sustainable value mapping, Asif's (2019) synergy framework, and the work of Boorsma et al. (2022) on circular design methodologies. The concepts were prototyped with Castor Ventures and Gorenje. Castor Ventures is a Dutch company specializing in manufacturing industrial pushcarts used by supermarket chains like Albert Heijn. Gorenje is a Slovenian major appliance manufacturer and is the fourth largest manufacturer of household appliances in Europe. The synthesis of the prototype sessions and the three PJM concepts resulted in the final PJM concept four, presented in the Product Journey Map playbook.

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1

Introduction

This section of the report will explain the problem statement, explain the objective, analyze the existing Product Journey Map, outline the content and requirements of a good methodology and provide a summary of the thesis content and the parties involved.

1.1 Problem statement

At this time, our linear economy urgently needs to transform towards a circular, less wasteful system to restrain the global environmental footprint of the products we use (Hans Bruyninckx, 2016). To move toward a circular economy, Bocken et al. (2015) identify three approaches: slowing resource loops, closing resource loops, and narrowing resource loops. Firstly, slowing resource loops extends a product's lifecycle through maintenance and repair, thereby extending the product's utilization period. Secondly, closing resource loops, through, for example, recycling, closes the loop between post-use and production, resulting in a circular flow of resources. Thirdly, narrowing resource loops refers to using fewer resources per product. To facilitate this transformation towards a circular economy, industrial designers need a complete and systematic way to map a product's lifecycle, a product journey map (PJM). Therefore, this graduation project aims to develop a PJM to help industrial designers identify opportunities to slow down and/or narrow down and/or close resource loops by systematically mapping the products' lifecycles.

A recent method that helps industrial designers analyze a product lifecycle is the PJM, published in the Delft Design Guide (Zijlstra, 2020). This PJM belongs to the category of journey mapping methodologies. Other forms of journey mapping include the customer journey map (CJM) (Heuchert, 2019) and the service blueprint (SB) (Bitner, 2008). These two methods can provide a theoretical basis to develop the PJM. Bocken (2016) and Evans & Yung (2019) present an alternative method of sustainable value mapping which designers can use to analyze the product journey. Asif (2019) presents a framework that can help designers determine the expected behavior, including end-of-life scenarios of products whose lifecycles can be extended. Lastly, the work of Boorsma et al. (2022) provides the basis for further improvement of Asif's (2019) framework. The synthesis of the literature above forms the basis of the final concept presented according to the five elements of method content (Daalhuizen, 2022) in the Product Journey Map playbook (Appendix. V).

1.2 Objectives of this thesis

The primary goal of the existing PJM is to enhance value capture from a product by improving the effectiveness and efficiency of each product usecycle. Here improving the effectiveness is defined as the degree to which the PJM improves the production of the desired result; success. Improving efficiency is defined as improving the outcome with the least wasted time, effort, and resources. Unfortunately, the structure of the PJM, as published in the Delft Design Guide (Zijlstra, 2020), does not support this goal as it does not provide means to analyze the effectiveness and efficiency of each usecycle. Furthermore, the visualization of the PJM is not actionable nor informative due to the lack of presented information. Therefore, these omissions; lack of a clear goal, formal structure, and actionable and informative visualization are the objectives and aim of this graduation project:

O1 Formulate a clear goal for the PJM.
O2 Develop a formal structure that supports the formulated goal.
O3 Create an actionable and informative visualization that industrial designers can use for internal communication, further development, and optimization of the product-service system.

1.3 Analyzing existing PJMs

Before this thesis, the PJM has seen two concepts. The first concept (figure 1) published in the Delft Design Guide (Zijlstra, 2020), aims to help industrial designers plan a product's journey over consecutive usecycles and identify potential service touchpoints and opportunities for capturing value. It analyzes the product by defining the number of usecycles that the product should last and their respective length. Subsequently, it creates a horizontal timeline and asks designers to determine service touchpoints, expected in-use repairs, product updates, delivery of consumables, forward and return logistics, and refurbishment activities.

The second PJM concept (Figure 2) made by the TU Delft Resource Efficient Circular Product-Service System (ReCiPSS) team aims to visualize the journey of a product throughout its lifetime, helping designers to prepare scenarios for a product's journey (Personal communication,

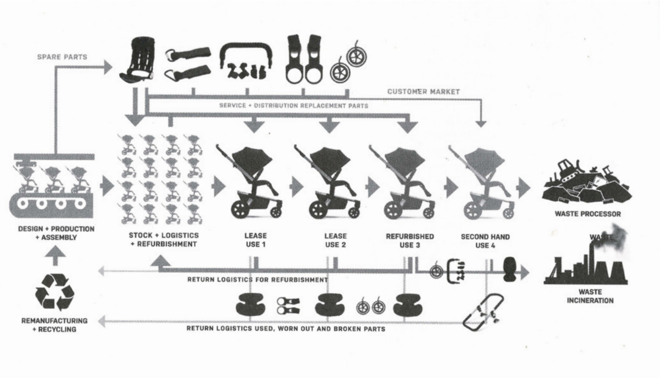


Figure 1: PJM Delft Design Guide

Boorsma, 2021). The PJM made by ReCiPSS aims to specify and detail interactions of the product with its stakeholders, e.g., customers, manufacturers, and network partners. By assigning individual swimlanes to each involved stakeholder, touchpoints can be matched with their respective stakeholder, organizing the whole journey to maximize visual communication (Bakker, 2017). It is a strategic method best used in the early stages of development.

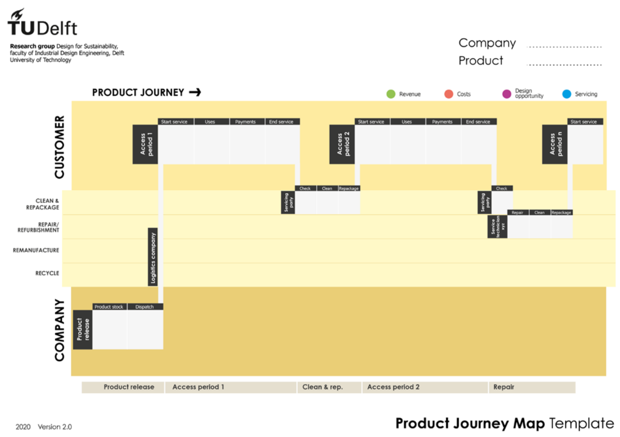


Figure 2: PJM ReCiPSS team

1.4 Content and requirements of a method

A design method describes a design activity that has been rationalized and abstracted from observations or imagined based upon theory (Daalhuizen, 2014). It will help industrial designers see the structure of the activity, extend their capabilities, and help communicate the outcome. Daalhuizens (2021) research presented a structured way to describe a design methodology. He advocates his five key elements to describe a design methodology's content: the method rationale, the method framing, the method goal, the method procedure, and the method mindset. Each element represents a different aspect of the design methodology. The method rationale explains why a method's goal is relevant and meaningful in its specific domain and context of use. The method framing further explains the context by describing how industrial designers can appropriately use the method in specific circumstances. These two elements are closely related as they help outline the appropriate context for the method. The method goal outlines the method's goal it tries to achieve, its scope, and the degree of flexibility. The method procedure explains how the method contributes to reaching the method's goal. Lastly, the method mindset describes the users' beliefs and prerequisite knowledge needed to use the method successfully and adequately.

In a previous paper, Daalhuizen (2014) states that using a method should be seen as a process in which two essential factors are accessibility and usability. The accessibility of a method is related to how easily a designer can access the method's description as a whole or parts of it. The method's usability describes its applicableness, referring to the format, such as illustrations, language, and examples of the method, and the additional information needed to use it properly, such as required prerequisite knowledge. My opinion is that the critical information and knowledge gained from using a method should be effectively and visually communicable as a coherent and cohesive visualization will help ensure the correct interpretation and implementation of findings and design opportunities. The information mentioned above, together with the information from the existing PJMs, form the basis of a set of requirements to develop and test a PJM:

- ☐ The PJM should provide industrial designers with a systematic structure to create a product lifecycle.
- ☐ The PJM should help industrial designers communicate the product's journey by visualizing the product's lifecycle in one illustration.
- ☐ The PJM helps industrial designers determine organizational actions at each stage in the product's lifecycle.

- ☐ The PJM helps industrial designers enhance value capture from a product by improving the effectiveness and efficiency of each product usecycle.

1.5 Summary of thesis content

This thesis contains six chapters. Chapter one introduces the problem statement, the research goal, relevant literature, and the involved parties. In the second chapter, the customer journey map (Heuchert, 2019) and service blueprint (Bitner, 2008) will be analyzed and assessed using the five elements of method content. Together with relevant literature, these analyses will provide the necessary theoretical background to design early concepts and, finally, a new PJM. The work of Bocken (2016), Evans & Yung (2019) on sustainable value mapping, and Asif (2019) on the synergy between strategic disciplines, product obsolescence, and End-of-life scenarios, will form the basis of the first PJM concepts 1 and 2 and are presented in chapter three. Chapter four will present concept 3, which will be prototyped and tested on the PJM requirements. In chapter five, the results of these prototype sessions, new insights on circular design methodologies (Boorsma et al., 2022), and discussion with the graduation team provide the improvements for the final concept 4, presented in the Product Journey Map playbook (Appendix V). Lastly, this graduation thesis will conclude with a reflection presented in chapter six.

1.6 Parties involved

TU Delft

Circular Product Design (CPD) is a research area of the Design Engineering department of the TU Delft Industrial Design Engineering faculty. The research team strives to explore new design strategies for the circular economy, investigating business models related to product life extension, reuse, refurbishing, and recycling (Bakker, 2019).

ReCiPPS

ReCiPPS, cofounded by the European Commission's Horizon 2020 research and innovation program, is composed of two large-scale demonstrators out of the automotive industry (Bosch) and white goods industry (Gorenje). Both Demonstrators hope to contribute toward a circular economy and create an example for other companies. ReCiPPS white goods industry demonstrator Gorenje will participate in a prototype session of the PJM, helping the TU Delft ReCiPPS team develop the PJM.

Castor Ventures

Castor Ventures is a Dutch company specializing in manufacturing industrial pushcarts used by supermarket chains such as Albert Heijn. Their products will be used to prototype the concepts of the PJM presented in this graduation thesis.

Gorenje

Gorenje is a Slovenian major appliance manufacturer and is the fourth largest manufacturer of household appliances in Europe. Gorenje's ambition during the ReCiPSS project is to deploy and pilot 400 long-lasting (at least 15.000 cycles) high-quality washing machines with Wi-Fi capabilities that can be successfully used in Product-as-a-Service models. Gorenje's products will be used to prototype the concepts of the PJM presented in this graduation thesis.

2

Analysis of existing methodologies

This chapter analyzes the Customer Journey Map (CJM) and the Service Blueprint (SB) using the five elements of method content. The customer journey map (CJM) is a methodology that helps designers understand the customer's decision process and knowledge by taking a customer's perspective and modeling their steps (Heuchert, 2019). Service Blueprinting is visually planning and organizing a business's resources to improve the employee's experience, directly and indirectly, and the customer's experience (Bitner, 2008). These two methods are studied because they visually outline journeys using symbols to represent actors and activities and, together with the PJM, are categorized as journey mapping methodologies (Zijlstra, 2020). By evaluating and presenting the CJM and SB using the five elements of method content, valuable information to be considered for the design vision of the PJM presented in 2.3 will be deducted in a structured way.

2.1 Customer Journey Mapping

2.1.1 Method rationale CJM

A good customer experience is critical. It provides a company with the opportunity to differentiate from the competition (Heuchert, 2019), and companies will most likely fail if they do not treat their customers well (Tempkin, 2010). While the importance of the customer experience is well understood, it is seldom translated into practice. The CJM (figure 3) is a methodology that helps designers understand the customer's decision process and knowledge by taking a customer's perspective and modeling their steps (Heuchert, 2019). They focus on human experiences, illustrating and visualizing the story of a specific actor as a sequence of steps (Stickdorn et al., 2019). Thereby enhancing and managing customer experiences and customer interactions, as seen from the customer's point of view (Ostrom et al., 2015). Although there is no common understanding of the overarching framework for the CJM, it is one of the most used visualization techniques within service design.

A lesson from the CJM's rationale for the PJM is the importance of understanding the journey from a specific actor's point of view. In the case of the PJM, this would be the product. Furthermore, the emphasis of the PJM should lie in illustrating and visualizing the story of this specific actor as a sequence of steps, providing users with a similar way to enhance and manage an actors' journey.

2.1.2 Method framing CJM

According to the Delft Design Guide (Zijlstra, 2020), the CJM can be helpful during several stages. In the early stages of the design process, the CJM can help understand customers' experiences with a product or a service. Customer journey maps can help make decisions on design directions or when ideating new solutions in the design process at later stages. Furthermore, Heuchert (2019) identifies two types of modeling contexts. Firstly, there are participatory workshops where multiple individuals participate in modeling activities. Secondly, there are isolated modeling contexts in which experts work with collected data to construct the CJM.

A lesson from the CJM's framing for the PJM is that the PJM can serve multiple purposes depending on the stage in the design process. Early on in the design process, PJMs can help understand the

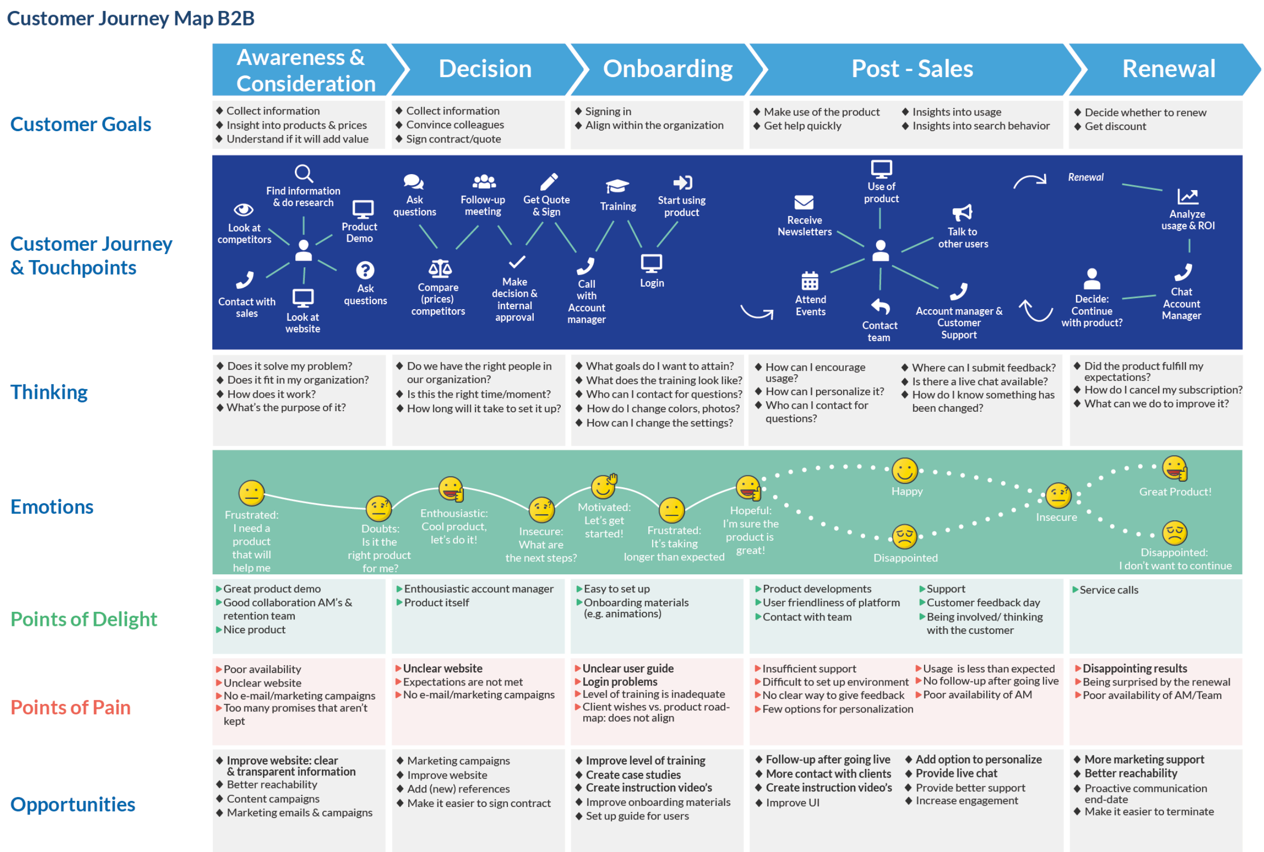


Figure 3: Example of a customer journey map (CJM) (Hoeberichts, 2018)

lifecycle of products, whereas later in the design process, they can help make decisions on design direction. Additionally, it is essential to consider who will use the PJM and in which context: participatory workshops or isolated modeling contexts. If the PJM is created and evaluated in participatory workshops, it requires less prerequisite knowledge. On the other hand, if the PJM is to be created and evaluated by experts in an isolated modeling context, it requires more prerequisite knowledge and could potentially address more complex subject matter.

2.1.3 Method goal CJM

Følstad and Kvale (2018) differentiate between as-is modeling a customer journey and creating a to-be customer journey. Although Følstad and Kvale (2018) differentiate between as-is and to-be, these activities do not need to be mutually exclusive. The goal of the CJM can be the analysis of present experiences, to trigger and generate input for the redesign of an existing service (as-is), or create new experiences from which a new service can be designed (to-be) (Heuchert, 2019). According to Heuchert, both the as-is CJM and to-be CJM result or entail service innovation.

These two approaches can also apply to the PJM. For example, an as-is PJM models an existing product journey and generates input to redesign the existing product journey. A to-be PJM could assist designers in mapping out a new product lifecycle over consecutive use cycles from which a new service can be designed. The as-is PJM and the to-be PJM will like the CJM result or entail product and/or service innovation.

2.1.4 Method procedure

Three critical issues and distinctions must be considered when formulating the method procedure. A CJM can have an active or a passive approach, it can be data or persona-driven, and choices for the visualization will have to be made and are further described below.

In the CMJ's method procedure, Heuchert (2019) distinguishes between the active and passive approaches. The passive approach finds existing problems or customer needs based on a developed CJM. The active approach finds new and novel service ideas by altering a CJM. These approaches correspond to the as-is CJM and to-be CJM, respectively. Usually, a to-be approach benefits from an active approach, altering a CJM to create new experiences from which a new service can be designed. Whereas the as-is approach benefits from the passive approach, finding existing problems or customer needs to trigger and generate input for redesigning an existing service.

Furthermore, a CJM can be data-driven or persona-driven. A data-driven CJM uses quantitative data, e.g., reviews or product polls, and analytical techniques. The persona-driven CJM is based on a persona that may utilize quantitative data but primarily relies on qualitative data, such as interviews.

The methods's visual nature further improves the usability of a CJM (Segelström, 2013). Using the horizontal axis to represent time makes the narrative of the visualization easy to read, ultimately allowing for multi-stakeholder communication. Følstad & Kvale (2018) also state that the integration of stages provides the user with guidance and clarity in the basic structure of a customer journey. Additionally, swimlanes make the visualization coherent, enabling the user to check each analyzed theme over the customer journey (Tax, 2013).

These issues and distinctions also apply to the PJM. A passive approach to the PJM will help find problems and pain points in the existing product's lifecycle. Combined with the as-is approach, it focuses on providing information for redesigning a product or service by identifying problems and pain points. Paint points are points of friction in the lifecycle, and in the PJM these could manifest themselves in the form of unclosed resource loops or high replacement frequencies of sub-assemblies. The as-is approach often has a passive approach combined with a data-driven approach. Examples of such data could include production rates, trade-in rates, take-back rates, remanufacturing rates, and recycling rates.

On the other hand, an active approach to the PJM will focus on altering the current product journey. In the literature mentioned above, the active approach is linked to the to-be type of customer journey mapping, focusing on creating and designing a new product or service. Hence, the active approach PJM aims to find new and novel ideas by altering the product journey. The to-be approach functions well with a persona-driven approach. As a result, if the PJM focuses on the to-be context, it will most likely take an active approach combined with a persona-driven approach. A persona-driven approach to the PJM will most likely look at a single product and map its journey over consecutive lifecycles. Furthermore, the persona-driven approach in the CJM primarily utilizes qualitative data. However, it occasionally may rely on quantitative data, indicating that the data-driven and persona-driven approaches may not necessarily be mutually exclusive. It is still unclear what the PJM's persona looks like, and therefore this will have to be explored in the concepts. Additionally, when creating a PJM, the data-driven and persona-driven approaches may not necessarily be mutually exclusive (figure 4).

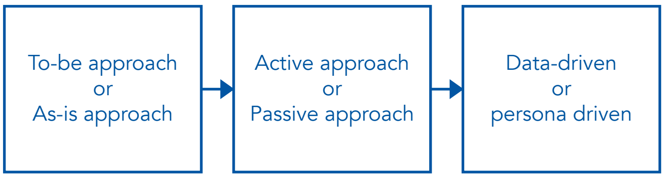


Figure 4: Considerations when formulating method procedure.

Integrating a horizontal axis representing time and the swimlanes to structure information will help the PJM effectively visualize and tell the product's story over its lifecycle. Furthermore, integrating stages appropriate to a product's lifecycle into the PJM could provide users with guidance and clarity.

2.1.5 Method mindset

The method mindset describes the users' beliefs and prerequisite knowledge needed to use the method successfully and adequately. It depends on the decisions made in the method framing, goal, and procedure. Depending on the type of CJM chosen (as-is or to-be), the mindset can differ dramatically. Heuchert (2019) also differentiates between two contexts in which the CJM can be made: a participatory-workshop environment and an isolated modeling context. These contexts directly impact the prerequisite knowledge to make the CJM. A participatory-workshop environment requires less prerequisite knowledge than in the isolated modeling context due to the direct involvement of customers.

For the PJM, it is essential to define the method framing, goal, and procedure, to be able to define the method mindset. Depending on the framing, goal, and procedure, a decision must be made on whether the PJM will be made in a participatory workshop or an isolated modeling context. This choice will affect the prerequisite knowledge and mindset necessary to create the PJM.

2.2 Service Blueprinting

2.2.1 Method rational service blueprint

Although the Service Blueprint (SB) is similar to the Customer Journey Map (CJM), it has one fundamental distinction; it is designed from the company and products perspective instead of the customer perspective (figure 5). Service blueprinting is the activity of planning and organizing a business's resources to improve the employee's experience, directly and indirectly, the customer's experience. Service blueprints give an organization a comprehensive understanding of its service and direct insight into the required underlying resources and processes. Service blueprinting is the most frequently used mapping tool used in service design (Gibbons, 2017).

Adopting a similar setup for the PJM will help designers define the required resources (people, props, processes) for the product's journey. Furthermore, this approach would be applicable in a to-be and as-is PJM setup. In the to-be PJM setup, an SB approach could help link various aspects, e.g., end-of-life scenarios and stakeholders, and support an active approach to see the consequences of changes made to the PJM. If applied to an as-is PJM, this setup could provide insight into why specific pain points are there and also help identify pain points.

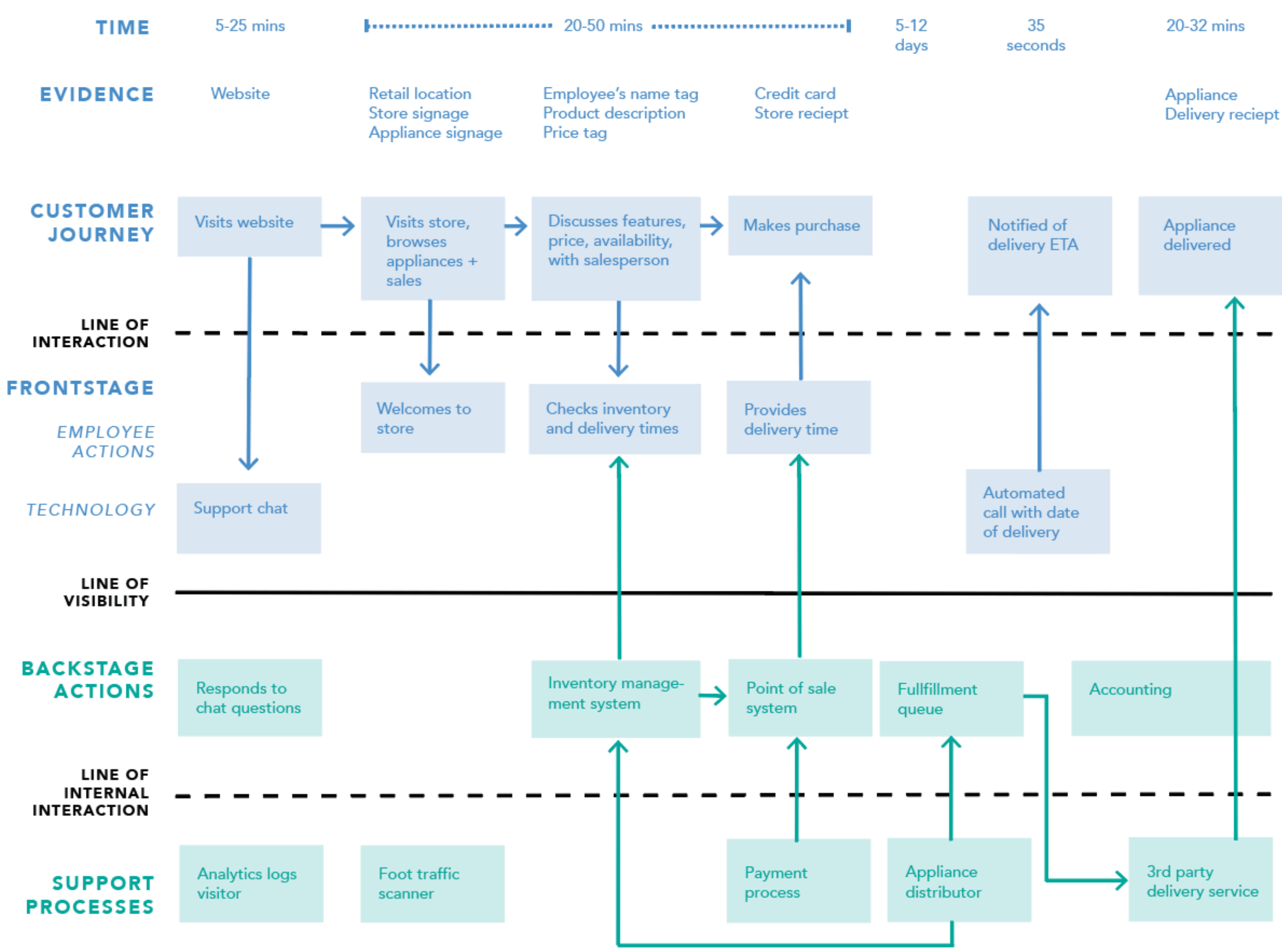


Figure 5: Example of a service blueprint (SB) (Gibbons, 2017)

2.2.2 Method framing

Service blueprinting results in a visual rendering of the service process and underlying organizational structure that everyone can see. Therefore it is instrumental in the concept and development stage of service development. According to Bitner (2008), when a new service development process progresses toward an actual design and implementation phase, the initial service idea must be made more concrete to be presented as a developed concept or even a rough prototype for customers and employees.

Like the CJM's framing, the SB's framing demonstrates that the PJM could serve multiple purposes depending on the stage in the design process.

2.2.3 Method goal

The "CJM's method goal" findings (as-is and to-be approach) can also be applied to the SB. In the early stages, as-is blueprints help understand the problem and identify current pain points, opportunities, and areas to focus on. In the middle stages of the design process, designers can use to-be service blueprints to ideate new processes, prototype future changes, and measure potential impact. At the end of the design cycle, service blueprinting provides insights for implementation, communicate changes, and can be used to benchmark. (Gibbons, 2017).

Like the CJM's framing, the SB's framing demonstrates that the PJM could take an as-is approach or a to-be approach. Additionally, depending on the stage of the development process, to-be and as-is PJMs are more suitable. For example, as-is PJMs help understand the problem at hand in the early stages, whereas, in later stages, to-be PJMs can help ideate new processes and possibilities. (Gibbons, 2017)

2.2.4 Method procedure

Service blueprints take different visual forms, some more graphic than others. Regardless of visual form and scope, every service blueprint consists of the same key elements. Bitner et al. (2008) propose the following key features to create a service blueprint:

Customer actions

The customer actions include the steps, choices, activities, and interactions that a customer performs while interacting with service to reach a particular goal. Like the service blueprint, the PJM can track the product's steps during its lifecycle, defining end-of-life scenarios, potential stakeholders involved, and service touchpoints. To determine the above, detailed information on the product might be required, such as a bill of materials or another way to deduce the lifecycle stagess such as production, reverse logistics, and recovery.

Frontstage actions

These are the actions that occur in the view of the customer. These include the actions and activities with contact employees, employees interacting with customers, or self-service technology, such as a mobile app. Translating frontstage actions to the PJM can provide insight into the activities such as end-of-life scenarios, transporting the product, or servicing the product.

Backstage actions

The backstage actions are the steps and activities behind the scenes that support front-stage actions. These actions could be performed by a backstage employee (e.g., a cook in the kitchen) or by a frontstage employee who does something not visible to the customer (e.g., a waiter entering an order into the kitchen display system). These actions would be appropriate in the PJM and would include ordering components, making orders, getting recall orders, and making the quotation. The processes and additional key elements required for the frontstage actions to be completed are further described below.

Processes

These are the internal steps and interactions that support the employees in delivering the service. Applied to the PJM, this would require designers to think about what they need to have or do to complete the backstage and frontstage actions.

Additional key elements

Furthermore, the service blueprint organizes the key elements into clusters with three separation lines. The first, the line of interaction, depicts the direct interactions between the customer and the organization. The second line, the line of visibility, separates all service activities visible to the customer from those not visible. Everything frontstage (visible) appears above this line, while backstage (not visible) appears below. The third line, the line of internal interaction, separates contact employees from those who do not directly support interactions with customers/users.

The concept of organizing key elements with separation lines applies to the PJM. For example, the line of visibility could separate the activities happening to the product from those happening behind the scenes to make the activities happening to the product possible. The line of internal interaction can separate the backstage actions from the processes needed to complete the backstage actions.

2.2.5 Method mindset

The prerequisite knowledge necessary for the service blueprint depends on the fidelity level needed. In the early stages of the design cycle, the fidelity can be lower, and hence less prerequisite knowledge is needed. Moving to later stages of the product development phase, where the service blueprint turns into an artifact used to communicate changes, the fidelity level changes, and information needs to be more precise as the process needs to be more detailed.

Translating this to the PJM, a PJM used in different stages of the design cycle will have various forms of fidelity and requires different levels of prerequisite knowledge. In early phases, PJMs fidelity can be lower and therefore need less prerequisite knowledge and vice versa.

2.3 Conclusion and design vision for the PJM

The analysis presented above of the CJM, the SB, and the PJM concepts mentioned in chapter 1.3 allowed me to envision the new PJM.

If the PJM takes an as-is approach, it will likely have a passive, data-driven approach focusing on discovering pain points and problems in the existing product journey. For these pain points and problems, designers can ideate solutions. In this case, the PJM will be data-driven and look to create a realistic representation of the present product journey, which requires data on the product's flow. If the PJM takes a to-be approach, it will most likely have an active, persona-based approach focusing on designing new service or product ideas by actively altering the PJM. After analyzing the CJM and SB mapping methodologies, it is still unclear what the "persona" in the PJM looks like. Therefore, this could or will be explored in the PJM concepts.

Both the to-be PJM approach and the as-is PJM approach can focus on slowing down, closing down, and narrowing loops. In the as-is PJM, solving discovered problems can slow down, close down, and narrow the loop. In the to-be PJM, creating the PJM will slow down the loop, as it will map a new extended lifecycle of the product. The active approach might result in additional new ideas that further close down, such as recycling or remanufacturing, and narrow the loop, such as product redesigns.

From a visual point of view, the PJM will share similarities with the CJM and service blueprint as they are all visual notations depicting business processes. Like the CJM and the SB, the PJM uses the horizontal axis to display time, as this will help the narrative of the visualization to be easy to read for all stakeholders. As used in the CJM, the integration of swimlanes will portray the visualization's information in an organized manner. As presented in the SB, lines of separation can help cluster the key information in a visual coherent, organized, and informative way?

3

Concepts of the PJM vision

This chapter presents the first concepts used to explore the PJM vision. In total, this graduation thesis contains four PJM concepts. These concepts were preceded by visual explorations of the PJM and are presented in appendix I, II, III, and IV for the interested reader. This chapter presents concepts 1 and 2. Concept 1 underwent a usability test with Castor Ventures, and its learnings provided the basis for concept 2. Concept 2 was prototyped with Gorenje, and the learnings from concept 2 provided the basis for concept 3. Concept 3 is presented according to the five elements of method content in chapter 4.0. Furthermore, concept 3 underwent a second usability test with Castor Ventures and Gorenje. The results of this usability test are incorporated into the final concept 4 presented in chapter 5.0.

3.1 Concept 1

3.1.1 Description of concept 1

Concept 1 is an as-is PJM (figure 8), meaning it forms the basis of redesigning an existing service. It has a passive approach as it attempts to help designers understand current pain points, identify opportunities, and align areas to focus on. Additionally, this concept of the PJM is data-driven as it tries to map the flow of products across the multiple-use cycles based on existing data, e.g., the number of products produced annually, the take-back rates, the remanufacturing rates, and the recycling rates. To develop the first PJM concept, I constructed a case about the NS Roetz bicycle using information from the Roetz website (Eilers, 2016), the Youtube channel of Roetz (2020), and the Rescom paper (Bakker, 2017). In creating this case, various assumptions using the data from the sources mentioned above: two thousand bikes were produced annually in 2015, from which 1000 bikes were remanufactured at the end of the usecycle. These bicycles would go through three usecycles of 5 years, resulting in a total lifecycle of 15 years. The end-of-life scenarios of the sub-assemblies for each usecycle can be found in figure 6 (Bakker, 2017).

Every stakeholder is unique and has its own needs and requirements. Given their various interests, different stakeholders will expect different things from a company, which can sometimes cause conflict. Furthermore, stakeholders sometimes act in limiting and sometimes enabling environments, meaning that the service setup can prevent a stakeholder from operating at maximum efficiency and effectiveness. By analyzing stakeholder-event-product interactions, we can turn the sometimes-limiting environment into a circular-enabling environment by identifying opportunities for the product to facilitate stakeholders' involvement. In other words, concept 1 attempts to increase the efficiency and effectiveness, of each stage in the lifecycle, by analyzing how the product and service (design) can facilitate the stakeholder's actions and goals during the product's lifecycle. Concept 1 first defines the stages in the product's lifecycle and plots these along the horizontal axis. Secondly, it describes the flow of the products over time, which can assist industrial designers in identifying pain points such as unclosed resource loops.

To visualize the product flow, the number of products (bicycles) was multiplied by the weight

Module	Strategic discipline	End-of-Cycle 1 (Year 5)		End-of-Cycle 2 (Year 10)	
		Private	Commuter	Private	Commuter
M01 - Frame	Operational excellence	Reuse	Reuse	Reuse	Reuse
M02 - Fork	Operational excellence	Reuse	Reuse	Reuse	Reuse
M03 - Electric hub	Product leadership	Replace upgrade	Replace upgrade	Replace upgrade	Replace upgrade
M04 - Carrier	Customer intimacy	Replace	Reuse	Replace	Reuse
M05 - Bell	Customer intimacy	Replace	Reuse	Replace	Reuse
M06 - Handle	Customer intimacy Operational excellence	Replace reuse	Replace reuse	Replace reuse	Replace reuse
M07 - Saddle	Customer intimacy	Replace	Replace	Replace	Replace
M08.1 - Transmission	Operational excellence	Reuse	Reuse	Reuse	Reuse
M08.2 - Paddling	Operational excellence	Reuse	Reuse	Reuse	Reuse
M09 - Wheel	Operational excellence	Reuse	Reuse	Reuse	Reuse
M10 - Tire	Customer intimacy	Replace	Replace	Replace	Replace
M11 - Light	Customer intimacy	Replace	Reuse	Replace	Reuse
M12 - Fender set	Customer intimacy	Replace	Reuse	Replace	Reuse
M13 - Brake	Operational excellence	Reuse	Reuse	Reuse	Reuse

Figure 6: Table containing sub-assemblies and their end-of-life-scenarios per usecycle (Bakker, 2017)

of the bicycles. The thickness of the line at the beginning of the diagram is equivalent to the annual production rate (2000 bicycles) multiplied by the weight of the product (16kg), resulting in 32000kg of units. In total, 1000 bicycles were remanufactured (16000 kg), and the assumption was made that the other 1000 bicycles (16000kg) ended up in the landfill. Using information from the Rescom Paper (2017), I estimated which sub-assemblies of the remanufactured bicycles would be recycled or sent to the landfill. This flow was calculated by multiplying the number of bicycles (1000 bicycles) by the weight of the individual sub-assemblies. For example, after the first usecycle, the handles, saddle, and tires were set to be recycled. Their combined weight was 3kg multiplied by 1000 units, resulting in 3000kg of recycled sub-assemblies. Using these basic calculations, I estimated and visualized a product flow across the product's lifecycle. The visualization was made by appropriately scaling the line thickness to the number of kilograms of the units. To accurately visualize the flow of products, data such as the number of products produced annually, the take-back rate at the end of each use cycle, remanufacturing rates, and recycling rates are necessary.

Additionally, the visualization is structured according to what I have called "the staircase principle". The diagram kinks downwards at the end of each usecycle unless part of the products is sent to the landfill. In the case of a perfectly circular system, the visualization would therefore resemble a staircase (figure 7). Nevertheless, as shown in figure 7, when products are sent to the landfill, the staircase stops, indicating an unclosed resource loop. After completing the visualization, the first concept of the PJM asks industrial designers to identify the stakeholders involved at each stage in the lifecycle by using the four standardized stakeholders as determined by Bocken (2019): environment, customer, network actors, society. The concept requires industrial designers to state the stakeholder's goals at each stage of the product's lifecycle. The identified goals can help designers brainstorm changes to the product design to make stakeholder-event-product interactions at each stage in the life cycle more efficient and effective. This concept also helps designers spot potential conflicts of interest between stakeholders, for example, when goals are not aligned, which could help decide which stakeholders to include and exclude.

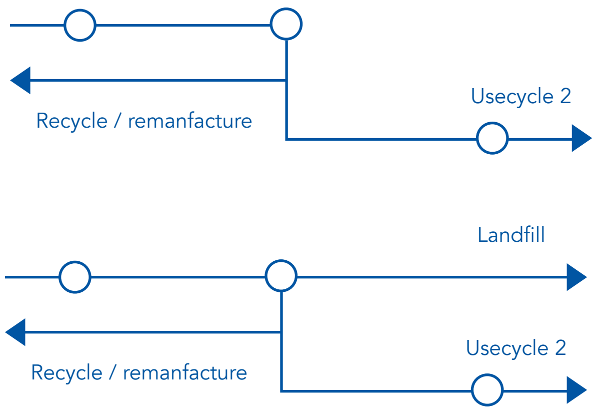
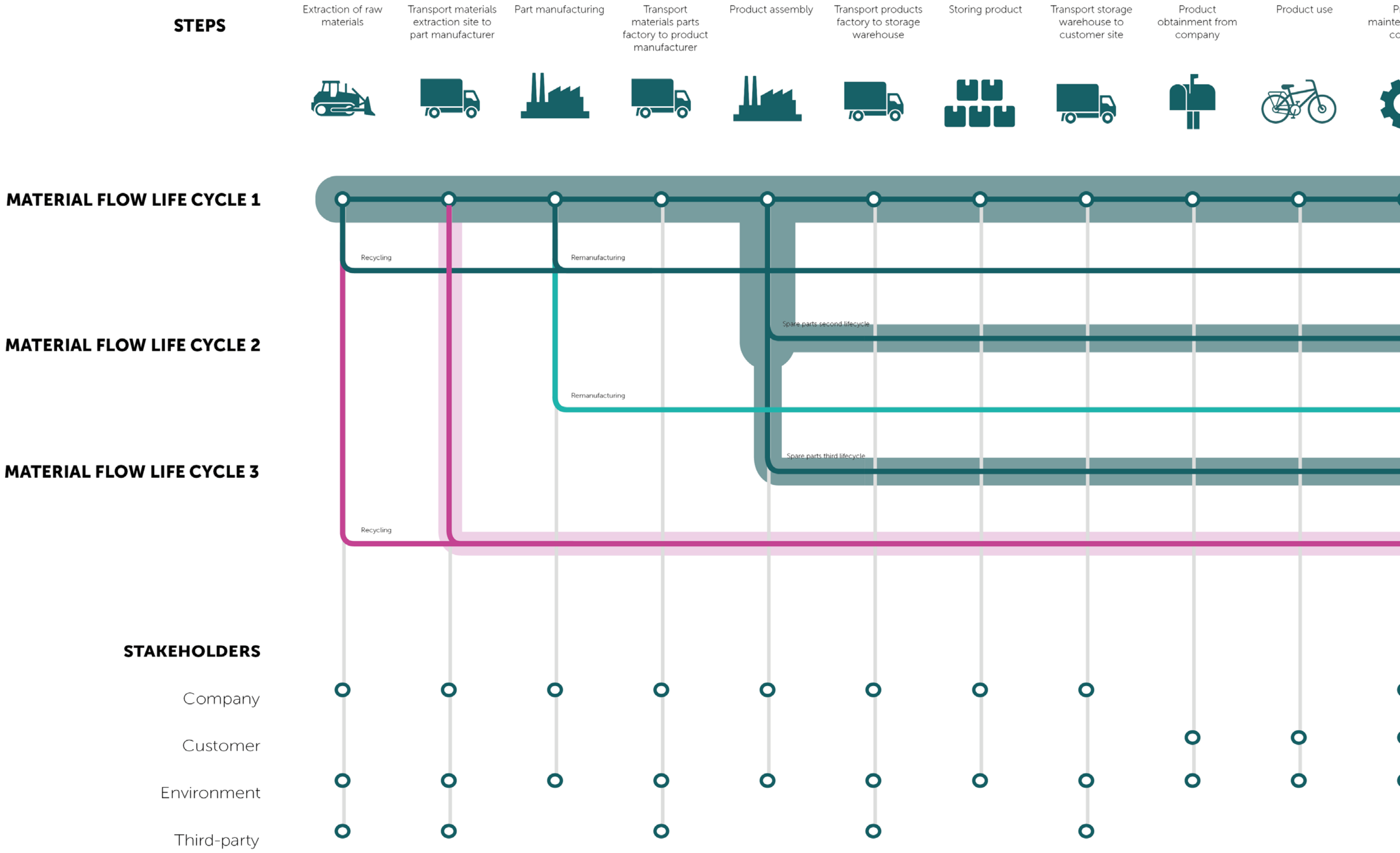


Figure 7: Staircase principle. The first image shows then thre is no proucts send to the landfill, creating a staircase.



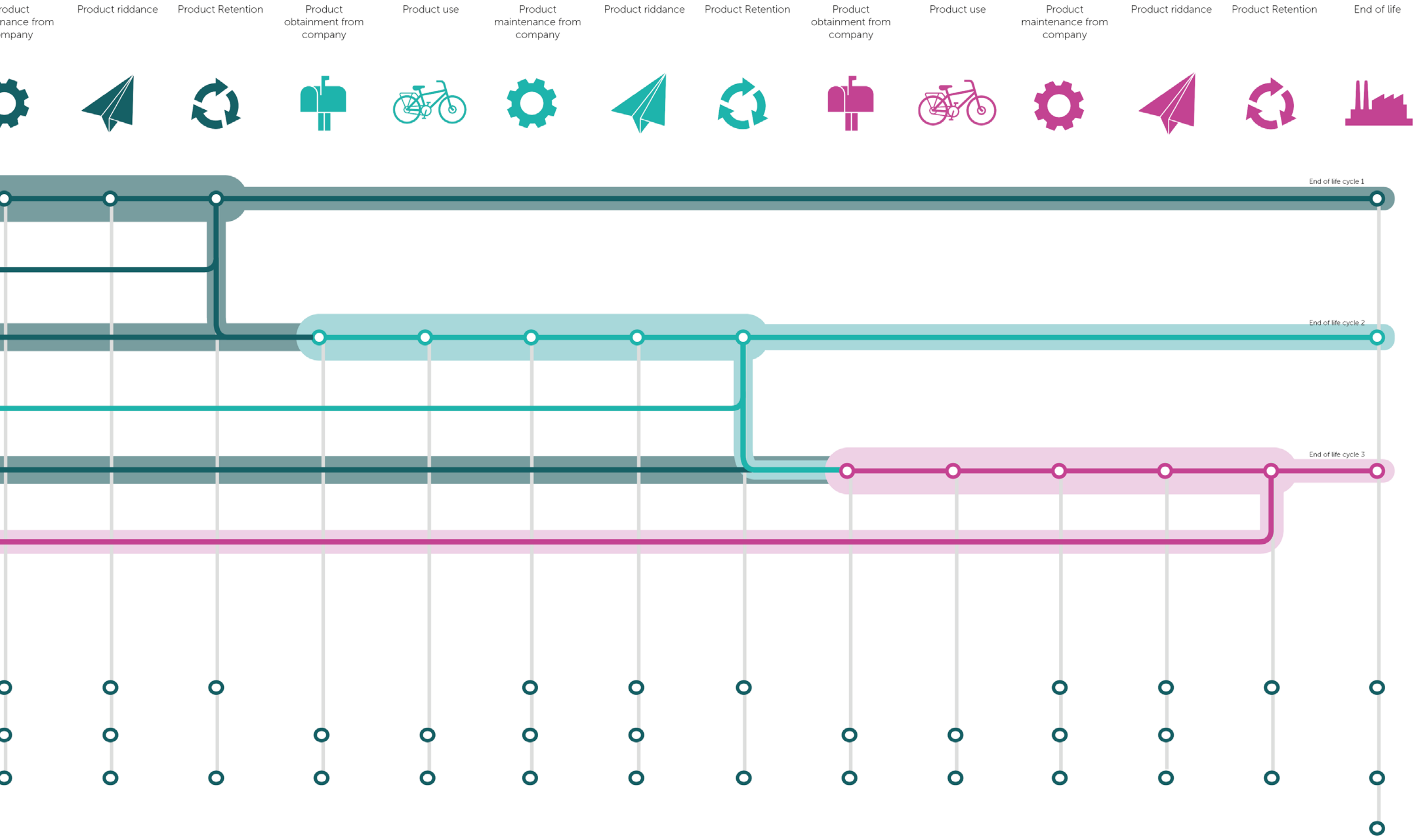
STAKEHOLDER GOALS

	Extraction of raw materials	Transport materials extraction site to part manufacturer	Part manufacturing	Transport materials parts factory to product manufacturer	Product assembly	Transport products factory to storage warehouse	Storing product	Transport storage warehouse to customer site	Product obtainment from company	Product use	
Company	Obtain material through minimal pollution Cheap materials	Minimize pollution via transportation Minimize transportation costs	Minimize machinery pollution Minimize energy usage Mimize producti-on costs	Minimize pollution via transportation Minimize transportation costs	Minimize machinery pollution Minimize energy usage and costs Assembly is streamlined	Minimize pollution via transportation Minimize transportation costs	Storing for minimal amount of time Minimal energy usage Minimal space occupatation	Minimize pollution via transportation Minimize transportation costs	Easy installation of product		Easy t Sh service p Chea mai
Customer									Fast obtainment of product Product should be affordable	Product should be easy to operate Product does not fail Product does what I want it to do	
Environment	Minimize pollution	Minimize pollution	Minimize pollution	Minimize pollution	Minimize pollution	Minimize pollution	Minimize pollution	Minimize pollution	Minimize pollution	Minimize pollution	Minimi
Third-party	Fast transportation Generate profit	Fast transportation Generate profit		Fast transportation Generate profit				Fast transportation Generate profit			

DESIGN OPPORTUNITIES

Extraction of raw materials	Transport materials extraction site to part manufacturer	Part manufacturing	Transport materials parts factory to product manufacturer	Product assembly	Transport products factory to storage warehouse	Storing product	Transport storage warehouse to customer site	Product obtainment from company	Product use	
Product can be made out of readily avaialbe materials The product can be made out of recycled materials Choosing circumastances the product is made in	Product should be easy to handle ((un)load)	Product should be easy to handle ((un)load) Product should be lightweight Product could be made out of local materials Product could be made with less material	Product should be easy to handle ((un)load) Product should be lightweight Product could be made out of local materials Parts should be made in same factory as products	Making product easy to assemble Product consists out of fewer parts Easy connection system	Product should be easy to handle ((un)load) Product should be lightweight Product could be made out of local materials Products should be stored in same factory as it is produced	Flatpack storage Product made on order (to a certain extent)	Product should be easy to handle ((un)load) Product should be lightweight	Product logistics Plug and play product style Does not require any construction Enough informaiton is provided on operating the product	Intuitive operation design NASA style redundance (if 1 system fails other takes over) Incorporated analytics to detected errors Provide informati-on on how to operate	Build r easy r if n Quality the

Figure 8: visualizati



o maintain ould be d as little as ossible p and fast ntenance	Get user to return the product	Easy dissassembly to core compo-nents for remanufacturing Easy to seperate materials for recycling	Easy installation of product		Easy to maintain Should be serviced as little as possible Cheap and fast maintenance	Get user to return the product	Easy dissassembly to core compo-nents for remanufacturing Easy to seperate materials for recycling	Easy installation of product		Easy to maintain Should be serviced as little as possible Cheap and fast maintenance	Get user to return the product	Easy dissassembly to core compo-nents for remanufacturing Easy to seperate materials for recycling	
	Return product with ease		Fast obtainment of product Product should be affordable	Product should be easy to operate Product does not fail Product does what I want it to do		Return product with ease		Fast obtainment of product Product should be affordable	Product should be easy to operate Product does not fail Product does what I want it to do		Return product with ease		
ze pollution	Minimize pollution	Minimize pollution	Minimize pollution	Minimize pollution	Minimize pollution	Minimize pollution	Minimize pollution	Minimize pollution	Minimize pollution	Minimize pollution	Minimize pollution	Minimize pollution	Minimize pollution
													Materials arrive on time Enough materials for profit are returned
modular for eplacement ecessary checks for product	Product has a return policy/ser-vice Product has no emotional attatchment	Product has litle steps to get to ciritcal compo-nents Connectios used in product are easy to loosen and fasten Reduce amount of unique materials used	Product logistics Plug and play product style Does not require any construction Enough informaiton is provided on operating the product	Intuitive operation design NASA style redundance (if 1 system fails other takes over) Incorporated analytics to detected errors Provide informati-on on how to operate	Build modular for easy replacement if necessary Quality checks for the product	Product has a return policy/ser-vice Product has no emotional attatchment	Product has litle steps to get to ciritcal compo-nents Connectios used in product are easy to loosen and fasten Reduce amount of unique materials used	Product logistics Plug and play product style Does not require any construction Enough informaiton is provided on operating the product	Intuitive operation design NASA style redundance (if 1 system fails other takes over) Incorporated analytics to detected errors Provide informati-on on how to operate	Build modular for easy replacement if necessary Quality checks for the product	Product has a return policy/ser-vice Product has no emotional attatchment	Product has litle steps to get to ciritcal compo-nents Connectios used in product are easy to loosen and fasten Reduce amount of unique materials used	

3.1.2 Learnings from concept 1

Concept 1 uses the standardized stakeholders identified by Bocken (2019). However, this appeared to be limiting instead of supporting designers in making decisions when using the PJM. The initial thought was that providing standardized stakeholders would help designers identify goals and streamline the thought process. Unfortunately, the standardization resulted in a loss of detail in identifying stakeholder goals and, indirectly, the description of the product journey. Reflecting upon this, in a concept focusing on stakeholder-event-product interactions, any loss in detail concerning the stakeholders will influence the completeness of the resultant PJM. Additionally, as previously mentioned, the stakeholder part was unspecific to the case due to a lack of data available on the product flow and the specific goals of the stakeholders.

Furthermore, this concept is data-driven, meaning it relies on quantitative data to map the flows of products. Nevertheless, this seemed to be a problem, as the required data is unavailable or not tracked. During a prototype session with Castor Ventures, a Dutch company specialized in manufacturing industrial pushcarts, the data (take-back rate, recycling rate, remanufacturing rate, lifecycle lengths of sub-assemblies) to complete the testing of this concept was not available. Additionally, in the prototype session with Gorenje, a company specializing in the white goods industry, the essential information was still being tracked and collected. Gorenje is a frontrunner in the circular economy and has been working on a circular implementation of their Asko washing machine for years. Therefore I concluded that a data-driven PJM is difficult to make. This also suggests that perhaps the PJM should take a to-be approach, mapping the expected product lifecycle over consecutive use cycles and serving as the basis for designing a new product or service. The data required for the as-is PJM concept 1 was difficult to attain or not available yet as these companies had not adopted the circular economy yet, in the case of Castor Ventures, or are still tracking and gathering the necessary data, in the case of Gorenje. Finally, the visualization did not provide specific information on which sub-assemblies were recycled, remanufactured, or sent to the landfill because of this lack of information.

3.2 Concept 2

3.2.1 Description of concept 2

Based on the learnings of concept 1, concept 2 is a to-be PJM (figure 11), mapping the expected product lifecycle over consecutive use cycles, serving as the basis for designing a new product or service. Concept 2 has an active approach that requires designers to alter the existing and created PJM to identify new opportunities. Unlike the PJM vision, this to-be PJM has a data-driven approach. Nevertheless, the data used in concept 2, the bill of materials, is readily available compared to the data in concept 1.

Part of the concept originated from discussions with Malvina Roci (Personal communication, 2021), a Ph.D. student at the KTH Stockholm. Roci's work with Asif (2019) on the synergy between strategic disciplines (subchapter 3.2.2), product obsolescence (subchapter 3.2.3), and end-of-life scenarios (subchapter 3.2.4) presented an opportunity for the to-be PJM to determine the expected product lifecycle on a sub-assembly level. These sub-chapters will explain the synergy discovered by Asif and Roci (2019), which are incorporated in concept 2 of the PJM. Lastly, subchapter 3.2.5 introduces the term sub-assembly categorizations and how this can help industrial designers decide on appropriate end-of-life scenarios and replacement frequencies.

Concept 2 maps the product life cycle of the Asko washing machine (Gorenje), extending the lifecycle to three usecycles of 5 years, slowing down the material loop (Bocken, 2019), and mapping the product's expected behavior over time. The Asko washing machine operates in a pay-per-wash business model.

3.2.2 Strategic disciplines

According to Treacy and Wiersma (1997), industrial designers constantly balance three competitive strategic disciplines when planning and designing a product: operational excellence, customer intimacy, and product leadership. Companies adopting an operational excellence discipline seek to minimize costs, reduce production steps, and optimize business processes, resulting in lean and efficient operations. Companies with a product leadership approach look for new solutions their latest product or service has previously solved. These companies attempt to produce state-of-the-art products and services. Companies focusing on customer intimacy concentrate on customizing the products and services to fit an increasingly acceptable definition of the customer. These companies focus on building customer loyalty and customization.

By applying these strategic disciplines on a sub-assembly level rather than a product level, Asif (2019) states that industrial designers will be able to balance strategic disciplines, assigning different strategies to different product sub-assemblies. A benefit of balancing the strategic disciplines is that it will allow us to understand better what the primary function is of each sub-assembly and what type of obsolescence it will undergo.

3.2.3 Product obsolescence

Den Hollander (2018) proposes to define a product's lifetime in terms of obsolescence. Burns (2010) states that products become obsolete when users no longer consider them valuable or significant. The three most common forms of obsolescence are emotional, technological, and functional obsolescence. (Asif 2019). When a product undergoes functional obsolescence, the particular product fails to carry out its function. For example, when a washing machine's counterweight cannot balance the tub during rotation, the sub-assembly undergoes functional obsolescence. Other forms of functional obsolescence include hygiene, where a product is deemed obsolete when it no longer meets hygienic standards (Kane et al., 2018). Introducing new aesthetic designs often triggers emotional obsolescence due to the users' desire for newness or lack of attachment to the product. For example, emotional obsolescence is triggered when an old iPhone model becomes less attractive to the user after the introduction of a new iPhone model. Technological obsolescence often results from a shift or advancement that makes an old product incompatible with new technologies. An example of technological obsolescence would be when CPU chips changed from 16 bits to 32 and then 64 bits. During this change, operating systems had to accommodate the older architecture.

These three forms of obsolescence are responsible for the disposal of most of the products used in everyday life. However, a product rarely faces all forms of obsolescence simultaneously. (Asif 2019) When a product faces emotional obsolescence, the product might still be functional. An example of this phenomenon is the electronic consumer market, where new designs with, sometimes minor, technological improvements often enter the market. These new designs make older product models less attractive to the consumer, even though they are perfectly functional. This example demonstrates that different product sub-assemblies face different obsolescence at different points in time.

According to Asif (2019), a connection exists between the strategic disciplines and the type of obsolescence it will most likely undergo. When companies design sub-assemblies for operational excellence, they design them for longevity, meaning the sub-assembly will function for as long as possible. Hence sub-assemblies designed for operational excellence will most likely undergo functional obsolescence. If companies design sub-assemblies for customer intimacy, they are designed to satisfy the users' desire for newness or overcome a lack of attachment to the product. Hence sub-assemblies designed for customer intimacy will most likely undergo emotional obsolescence. Lastly, when companies design sub-assemblies for technological leadership, they are constantly at the state-of-the-art level. The introduction of new or upgraded versions of the sub-assembly is frequent. These new versions are solutions to the problems the former sub-assembly has previously solved. Therefore, sub-assemblies designed for technological leadership will most likely undergo technological obsolescence.

3.2.4 End-of-life scenario

Asif (2019) further determines a correlation between product obsolescence and EoL scenarios. According to Asif (2019), sub-assemblies that face technological obsolescence are the candidates for upgrading operations at the end of predefined lifecycles. In some cases, upgrading can mean replacing the old sub-assembly with new ones compatible with the latest technologies. Similarly, sub-assemblies prone to emotional obsolescence need to be replaced with other sub-assemblies to give a completely new look. Sub-assemblies prone to face functional obsolescence are candidates for reusing at the end of the predefined lifecycles. These sub-assemblies face functional obsolescence long after technological and emotional obsolescence.

Ong (2016) further details the assignable end-of-life scenarios by identifying that moving subassemblies need replacement more often and moving subassemblies with a high intrinsic value, e.g., shafts and gears, should be remanufactured. Boorsma (2022) adds that sub-assemblies with high intrinsic value make the reverse logistics and remanufacturing process viable from a cost perspective.

Furthermore, for fixed sub-assemblies, e.g., engine block and alternator cover, Ong (2016) states the end-of-life treatment is subject to change as the actual physical condition of the sub-assembly requires assessment. If this sub-assembly is of high-intrinsic value, it should also be remanufactured. Further EoL scenarios include recycling and incineration with energy recovery (Granta Edupack, 2022). These two end-of-life scenarios need consideration when sub-assemblies are replaced but not remanufactured. In conclusion, assigning different strategic disciplines to sub-assemblies and applying their synergy with the concepts of obsolescence and end-of-life scenarios allows users to plan out product life cycles strategically. Figure 9 provides an overview of the synergy.

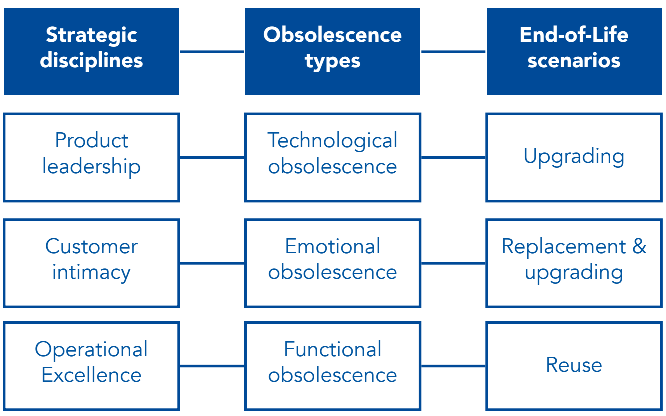


Figure 9: Asif's synergy between strategic disciplines, obsolescence types and end-of-life sceanrios.

3.2.5 Sub-assembly categorizations

This sub-chapter introduces four sub-assembly categorizations to assist the designer in making the to-be PJM. These sub-assembly categories have been inspired by the Hotspotmapping tool by Bas Flipsen (2012), Boorsma et al. (2020), and Bracquené et al. (2018) and help industrial designers identify appropriate end-of-life scenarios and replacement frequencies.

Key function and key failure category

Bracquené et al. (2018) define priority parts by their functional importance and replacement frequency. Hence, key function parts are parts with high functional importance, and key failure parts are prone to high failure rates. Key failure parts must be easy to replace due to their high replacement frequency. Where Bracquené et al. (2018) refer to parts, this thesis applies his definition to "sub-assemblies." Icons visualize and serve as indicators in the product journey map visualization (figure 10).

High-value category

High-value sub-assemblies have a high intrinsic value and make the reverse logistics and remanufacturing process viable from a cost perspective (Boorsma et al., 2022). Furthermore, they are determined using a calculation from the "Hotspot-mapping" tool by Flipsen (2012). From a personal communication (Flipsen, 2022), he explains that the total value is an indication rather than an exact number:

Value sub-assembly = price material ($/kg) * weight (kg)

Sub-assemblies are flagged when the sub-assembly has the highest value, where the 80th percentile colors yellow and the 90th percentile colors red.

An icon that visualizes this category in the PJM can serve as an indicator or starting point in the active approach of this to-be PJM (figure 12, chapter 4).

High-impact category

High impact sub-assemblies are sub-assemblies with a high CO2 footprint. Flipsen (2012) identifies these sub-assemblies using a calculation from the Hotspotmapping tool. Like the high-value sub-assembly, the calculation is an indication rather than an exact number:

Impact sub-assembly = embodied CO2 material (C02/kg) * weight (kg)

Sub-assemblies are flagged when the sub-assembly has the highest CO2 footprint value, where the 80th percentile colors yellow and the 90th percentile colors red. An icon that visualizes this category in the PJM can serve as an indicator or starting point in the active approach of this to-be PJM (figure 11).

The method analyzes the product on a sub-assembly level, detailing the lifecycle of each sub-assembly. Doing so creates an overview of the expected product lifecycle journey. Firstly, the sub-assemblies are categorized as mentioned above. Then, the PJM assigns each sub-assembly to a strategic discipline that determines the appropriate product obsolescence type and subsequent end-of-life scenario. Based on the tangible state of the product, it forces designers to consider adjusting the product's value proposition

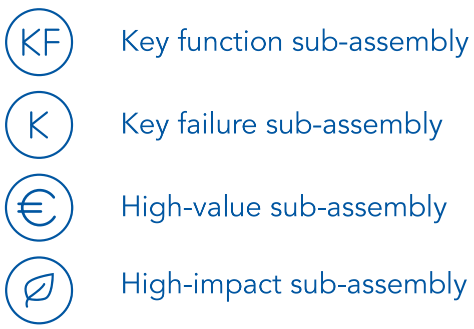


Figure 10: Icons to indicate the key failure, key function, high impact and high-value sub-assembly categorizations.

by compensating for the tangible loss in product quality with intangible value in the product price. This way, a company can potentially reach a larger market share, as more target audiences can access the product.

3.2.6 Learnings of concept 2

Unfortunately, the prototype session with Gorenje did not result in the expected outcome. From the conversations with representatives from Gorenje, it became clear that the company has already been working on circular product implementation for some years. Hence the test case was a mismatch with the tool. Additionally, the PJM concept 2 and its visualization did not provide enough information about the sub-assemblies across their lifecycle. Furthermore, inspired by Den Hollander (2018), this concept attempts to determine the value proposition based on the tangible state of the product's sub-assemblies. However, value propositions derive from the product as a whole and not the sum of its sub-assemblies. Therefore, determining the value proposition through the tangible state of the product is removed in concept 3. Lastly, this concept determined the stakeholders, but it did not provide additional information on why they were involved, e.g., their function. The PJM can use the individual sub-assembly swimlanes to outline the stakeholders' actions required at each stage on the vertical axis, similar to the line of the interaction used in the service blueprint.

Asko Professional washing machine

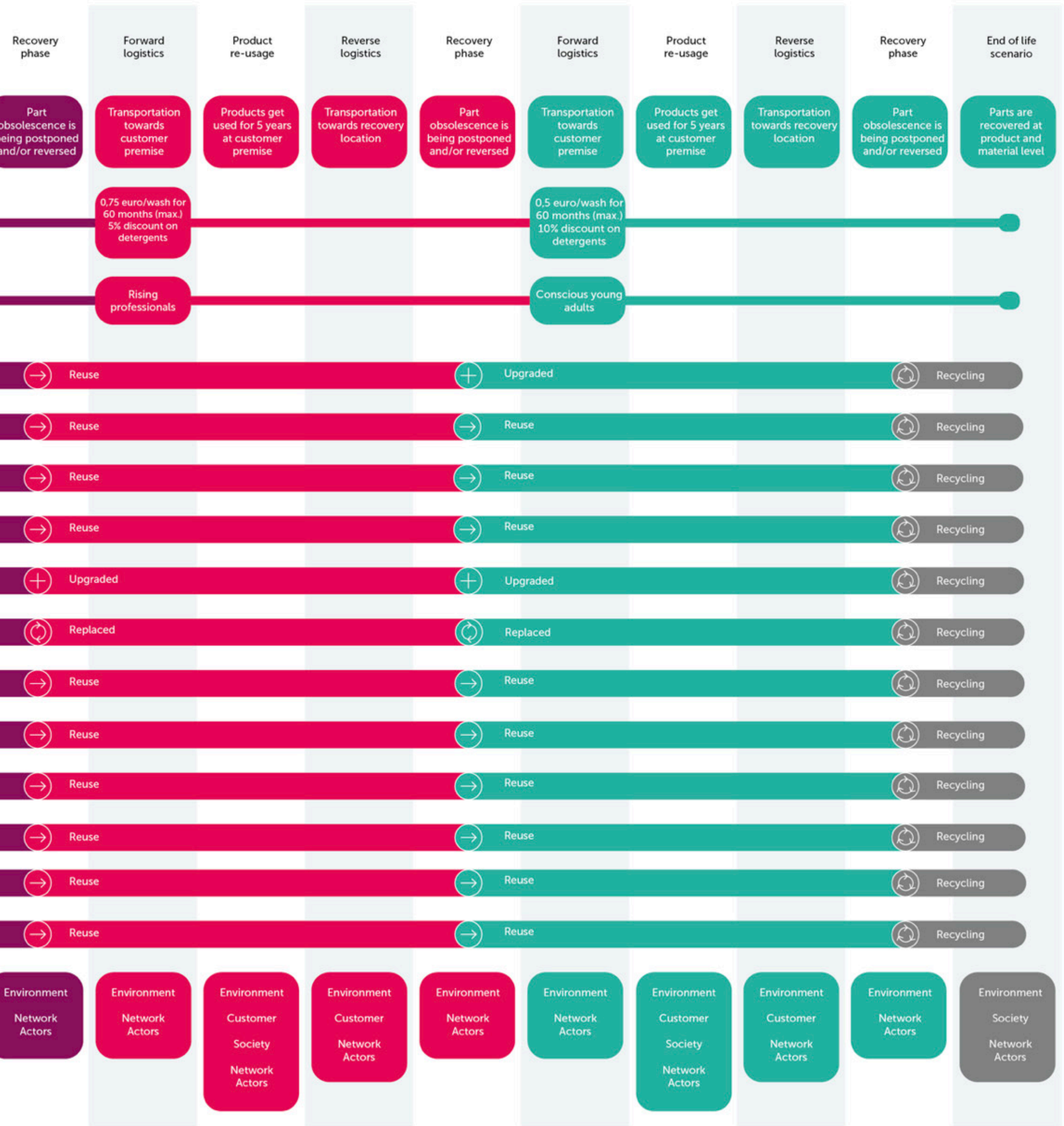
Legend:

- Environmental parts
- Economic parts
- Key parts
- Direct reuse
- Replace
- Remanufacture
- Recycle
- Repair
- Upgraded

Stages	Extraction of raw materials	Forward logistics	Part production	Forward logistics	Product production	Forward logistics	Product usage	Reverse logistics
Context	Raw material being extracted in large industrial prodution plants	Transportation towards part production plant	Production plants all across the world	Transportation towards product production plant	Production plants all across the world.	Transportation towards customer premise	Products get used for 5 years at customer premise	Transportation towards recovery location
Longitudinal value proposition	1 euro/wash for 60 months (max.) 0% discount on detergents							
Customer segment	Prosporous professionals							
Module 1	Motor (Environmental parts, Economic parts, Key parts)							
Module 2	Transmission (Key parts)							
Module 3	Support (Key parts)							
Module 4	Drum (Key parts)							
Module 5	Control unit (Key parts)							
Module 6	Door							
Module 7	Inlet							
Module 8	Temperature regulator (Environmental parts)							
Module 9	Front, side and top panel							
Module 10	Rear panel							
Module 11	Holder							
Module 12	Drain							
Stakeholders & Key partners	Environment, Society, Network Actors	Environment, Network Actors	Environment, Network Actors	Environment, Network Actors	Environment, Network Actors	Environment, Network Actors	Environment, Customer, Society, Network Actors	Environment, Customer, Network Actors

Figure 11: Visual

gorenje
Life Simplified



ization of PJM concept 3

4

Concept 3 of the PJM vision

Learnings from testing concept 2 with Gorenje were implemented and led to Concept 3, an improved version of concept 2. This new improved concept 3 was tested again with Castor ventures to map out the product life cycle of the Castor Ventures Strekkar. Castor Ventures is a Dutch company specializing in manufacturing industrial pushcarts. Supermarket chains, such as Albert Heijn, use these carts to move their goods from distribution centers to supermarkets. Currently, their pushcart has a life expectancy of 10 years. When damaged or worn, these carts are brought back for repair in exchange for a fee.

4.1 Implementation of learnings concept 2

Concept 2 provided me with two learnings that I implemented in concept 3 (figure 17). The visualization did not give enough insight into the sub-assembly's lifecycles. Concept 2 did not provide enough information about the stakeholders' tasks and involvement within the products lifecycle. Therefore, these two insights were implemented in concept 3 and are further described below.

To provide more insight into the sub-assemblies lifecycle, concept 3 of the PJM calculates their CO2 footprints across their entire lifecycle. These CO2 footprint calculations for the PJM are based on the Eco Audit of the Granta Edupack program (2022). This program is a database of materials, process information, material selection tools, and provides information on supporting resources. The calculations are adjusted to make them cumulative, meaning that the CO2 footprint can never have a negative value. I think this will be the correct representation for the sub-assemblies' CO2 footprints over time. At the end of the lifecycle, these impacts are clear, and designers can immediately compare the CO2 footprint of sub-assemblies. The CO2 footprint calculations for every end-of-life scenario used in this concept are outlined below and are as follows:

- ☐ CO2 Indicator = CO2 Embodied * weight of sub-assembly
- ☐ CO2 Recycling = CO2 Recycling primary material * weight of sub-assembly
- ☐ CO2 Remanufacturing = 0.21 kg/kg of CO2. According to Granta Edupack, the amount of CO2 the remanufacturing process produces.
- ☐ CO2 Service = 0.21 kg/kg of CO2. I assumed that the CO2 footprint of remanufacturing would be similar to servicing.
- ☐ CO2 Reuse = 0. When directly reusing the sub-assemblies does not add to the CO2 footprint of the sub-assembly.
- ☐ CO2 Replace = CO2 Embodied * weight of sub-assembly
- ☐ CO2 Combustion = CO2 combustion * weight of sub-assembly

To provide designers with more information on the stakeholders, concept 3 of the PJM identifies the appropriate stages, the involved stakeholders, and their actions in writing (verb-noun combination, e.g., deliver product). This addition to concept 3 allows designers to generate a list of activities necessary to support the new extended product lifecycle. Similar to the Service blueprinting, these activities will be separated from the sub-assembly lifecycles by a line of activity, organizing the key elements of the PJM.

4.2 Method rational concept 3

Concept 3 of the PJM provides designers with the tools to extend a product's lifecycle and map the expected behavior, slowing down the material loop and putting the product center stage. This concept of the PJM has a to-be, data-driven, active approach. The generated PJM, using concept 3, can be changed to map the desired product behavior by using an active approach. For example, companies can identify alternatives that close the material loop by looking for non-recycled sub-assemblies. Additionally, sub-assemblies with high-CO2 footprints can easily be identified through the calculations, further analyzed, and redesigned to lower the CO2 footprint. Because concept 3 links the stages in the product's lifecycle to actions performed by stakeholders, designers can directly analyze the effects of changes made on the stakeholder(s) side and vice versa. Lastly, it can serve as input for other methodologies such as life cycle assessments (LCA). Den Hollander states that methodologies such as the LCA require product life cycle scenarios as input for their calculations. However, these methodologies cannot be used to generate these scenarios themselves.

4.3 Method framing concept 3

Concept 3 of the PJM is a planned visual rendering of the product's expected lifecycle and underlying structure. It extends the product's lifecycle, slowing down the material loop, and opportunities can be identified to close or narrow the loop. The approach of concept 3 is data-driven and is best used in later stages of the design cycle as designers require a product's bill of materials, including material and weight. Since the tool requires prerequisite knowledge of strategic disciplines, product obsolescence, EoL scenarios, information databases (Granta Edupack), use cycles, and life cycles, professionals should conduct the initial phase of creating the PJM in an isolated setting. Afterward, a session setting involving multiple stakeholders can be used to change the PJM and to ideate for new service ideas through an active approach.

4.4 Method goal concept 3

This concept of the PJM assists designers extend the lifecycle of a product and mapping the expected behavior. With the to-be approach, the PJM serves as the basis for designers to create a new product or service. It helps industrial designers develop a sensible starting point to determine the lifecycle of the products, their environmental impact, the necessary stakeholders, and their subsequent actions, assisting designers in further narrowing and closing the loop.

4.5 Method procedure concept 3

In the following steps, the method procedure is described. Steps 1-9 are concerned with generating input, and steps 10-13 visualize the input.

Step 1

This step identifies the sub-assemblies of the product. Sub-assemblies in this thesis are defined as part clusters that are easy to disassemble from a product as a whole, have limited connectors to the other components, and often support the same product function. Such part clusters tend to have a comparable lifetime expectancy. The product architecture typically prescribes what the subassemblies of a product are. Note down the following information for the sub-assemblies (figure 12):

- ☐ Name the sub-assemblies
- ☐ Determine the sub-assembly weights
- ☐ Specify the primary material(s) used in the sub-assembly

Step 2

Specify the (potential) length of the product lifetime in years or months. Afterward, specify the (potential) number of use cycles and their length in years or months.

Step 3

Using the bill of materials, identify key failure sub-assemblies that require frequent replacement and key function sub-assemblies that are vital to the product's functionality. Sub-assemblies that are categorized as key failure sub-assemblies often include moving sub-assemblies and sub-assemblies that have to endure heavy loads. These sub-assemblies will be tagged with an icon in their respective swimlanes (figure 10, chapter 3).

Step 4

Using the bill of materials, calculate the intrinsic value of the sub-assemblies. Use the prices of the sub-assemblies if they are available, if not, make a cost estimation. Sub-assemblies are flagged when the sub-assembly has the highest intrinsic value, where above the 80th percentile colors yellow and above the 90th percentile colors red (figure 12). The flagged sub-assemblies will receive the high intrinsic sub-assembly icon in the visualization (figure 10, chapter 3).

Step 5

Using the bill of materials, calculate the product sub-assemblies CO2 footprints. Use the CO2 footprint of the sub-assemblies' primary material (CO2/kg) and its weight (kg) to estimate the CO2 footprint. Sub-assemblies are flagged when the sub-assembly has the highest CO2 footprint, where above the 80th percentile colors yellow and above the 90th percentile colors red (figure 12). The flagged sub-assemblies will receive the high-impact sub-assembly icon in the visualization (figure 10, chapter 3).

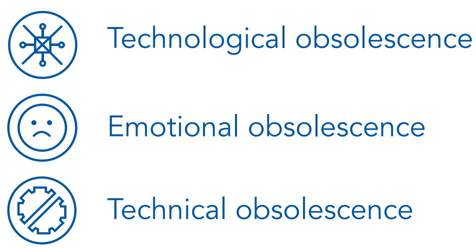


Figure 13: Icons for obsolescence types

Sub-assembly number	Sub-assembly name	Sub-assembly primary material	Sub-assembly weight	Sub-assembly impact	Sub-assembly value
1	Sub-assembly A	Material A	X kg	100 CO2 kg/kg	€ 100
2	Sub-assembly B	Material B	Y kg	90 CO2 kg/kg	€ 90
3	Sub-assembly C	Material C	Z kg	80 CO2 kg/kg	€ 80
4	Sub-assembly D	Material D	C kg	70 CO2 kg/kg	€ 70
5	Sub-assembly E	Material E	V kg	60 CO2 kg/kg	€ 60

Figure 12: Table showcasing how to structure information and highlighting sub-assemblies at the highest, 90 and 80th percentile.

Step 6

Define the strategic disciplines and corresponding product obsolescence type for each sub-assembly. The synergy between the concept of strategic disciplines and product obsolescence will be used to determine how long each sub-assembly will last in step 7.

Step 7

Determine how many use cycles each sub-assembly will last using the information generated in the previous steps. For example, sub-assemblies as key failure sub-assemblies or prone to emotional obsolescence will likely need replacement first. On the other hand, sub-assemblies prone to functional obsolescence will last more use cycles.

Step 8

Based on the strategic disciplines, obsolescence types, and sub-assembly categorizations, assign end-of-life scenarios to the sub-assemblies. If sub-assemblies are prone to technological obsolescence, they are candidates for upgrading or replacment operations at the end of predefined lifecycles. Similarly, sub-assemblies prone to emotional obsolescence need to be replaced with aesthetically different sub-assemblies or upgraded to give a new look. Finally, sub-assemblies prone to face functional obsolescence are candidates for reusing at the end of the predefined use cycles. These sub-assemblies will last the longest and face functional obsolescence after technological and emotional obsolescence. Furthermore, if sub-assemblies require replacement, their end-of-life scenario are either recycling, remanufacturing, or combustion with energy recovery (figure 14).

Step 9

Define the product life cycle stages, knowing how many use cycles each sub-assembly can last, create

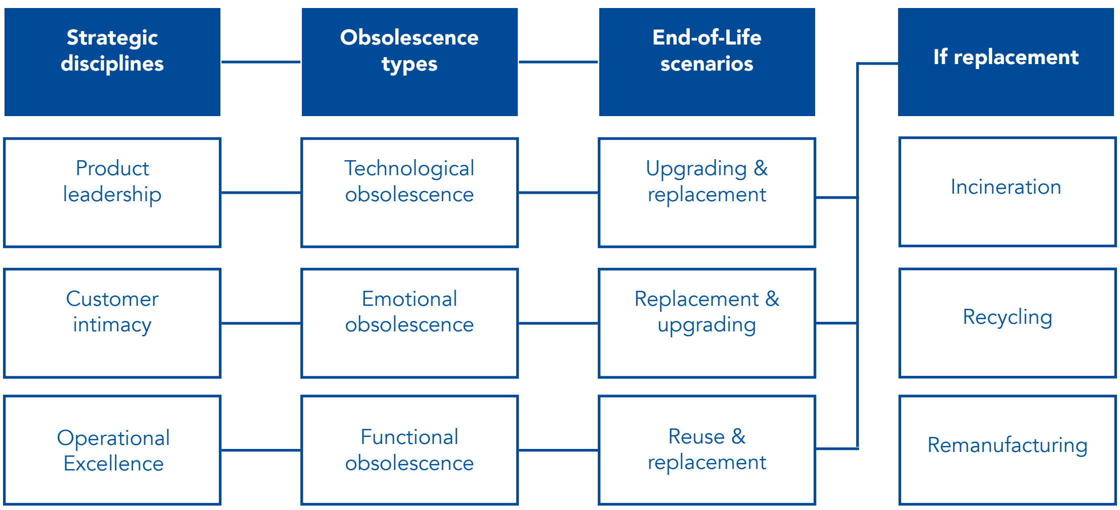


Figure 14: Overview of the updated synergy between strategic disciplines, obsolescence types and end-of-life scnearios.

service points if needed, and otherwise fill in at the end of each use cycle which End-of-Life scenario the sub-assembly will undergo. Put these on the horizontal axis in chronological order.

Step10

Create a horizontal timeline and swimlane for each sub-assembly. At the beginning of each swimlane, indicate the sub-assembly categories and obsolescence type with the correct icons (figure 13). Place the icons for the EoL scenarios, illustrated in figure 15, at the appropriate stages. If a sub-assembly gets replaced, the timeline needs to kink downwards, indicating the placement of a new sub-assembly (figure 17).

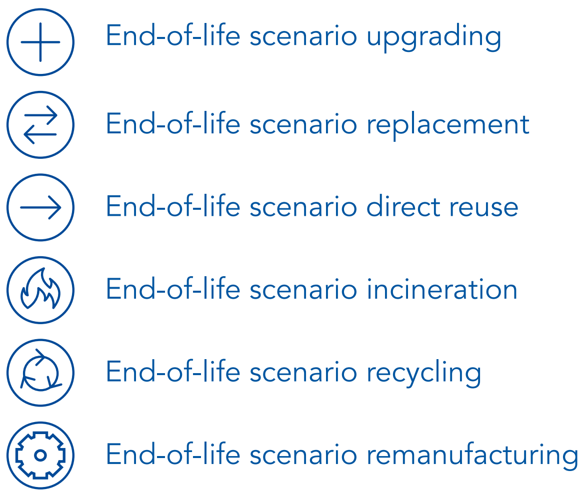


Figure 15: Overview of end-of-life scenario icons

Step 11

Calculate the CO2 footprint over the lifecycle of the sub-assemblies. Use the following equations:

- ☐ CO2 Indicator = CO2 Embodied * weight of sub-assembly
- ☐ CO2 Recycling = CO2 Recycling primary material * weight of sub-assembly
- ☐ CO2 Remanufacturing = 0.21 kg/kg
- ☐ CO2 Service = 0.21 kg/kg
- ☐ CO2 Reuse = 0 kg/kg.
- ☐ CO2 Replace = CO2 Embodied * weight of sub-assembly
- ☐ CO2 Combustion = CO2 combustion * weight of sub-assembly

Visualize the amount of the CO2 footprint using the thickness of the line, as shown in figure 16. The thickness of the line is directly linked to the CO2 footprint amount. For example, if the CO2 footprint of sub-assembly A is 50CO2/kg and the CO2 footprint of sub-assembly B is 15 CO2/kg, then the line thickness of sub-assembly A is 50, and the line thickness of sub-assembly B is 16.

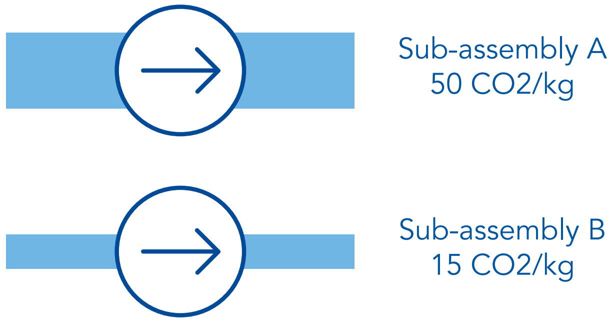


Figure 16: Thickness of the line indicating the CO2 footprint of the Sub-assembly.

Step 12

For each stage, write down the actions required by the stakeholders in a verb-noun combination. Find the stakeholders needed to complete the actions. Underneath the line of interaction (figure 17), create a swimlane for each identified stakeholder, order the activities appropriately and place the activities in the correct order.

4.6 Interpreting the visualization

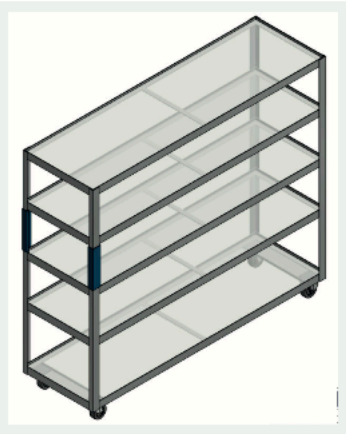
The visualization should be read as a timeline, in which each usecycle is represented by a different color. In figure 17, the first use cycle is green, the second use cycle is red, and yellow is used for the third use cycle. The sub-assembly with the most significant CO2 footprint is at the top of the visualization and can serve as a starting point for the active approach to this PJM concept. By reading each swimlane as a timeline, users can identify what happens to the sub-assembly. The CO2 footprint of the body can act as an indication of where significant opportunities for reduction are located. Here companies could look for alternative materials or extend the sub-assemblies' lifecycle to prevent frequent replacement. The required stakeholder actions are paired vertically to each stage. By actively changing the sub-assembly journey section of the PJM, users can see how this will impact the stakeholders' side of the PJM. For example, new stakeholders might be needed if the sub-assembly materials are changed.

Every swimlane reads from left to right, providing the user with the following information: to which categories does the sub-assembly belong, which obsolescence type it will undergo, what happens to the sub-assembly over time, and what the end of life scenario will be. With this information in mind, designers can decide which part of the journey they would like to change using the active approach. Furthermore, designers can directly see the consequences of the changes to the sub-assembly for the stakeholders and vice versa. For example, during the prototype session with Castor Ventures, the company representative considered replacing the acrylic plates with wooden panels and opted for more durable wheels. This implied that the stakeholder Vink, responsible for the acrylic plates, would no longer be necessary (figure 17). Similarly, the stakeholder Tente, responsible for the wheels, might also be replaced as wheels with increased durability might come from a different company.

4.7 Method mindset

PJM concept 3 has a to-be, active, data-driven approach. This means that the user needs prerequisite knowledge and access to information on the product, the strategic disciplines (customer intimacy, product leadership, operational excellence), product obsolescence, EoL scenarios, and information databases (e.g., Granta Edupack), usecycles, lifecycles as well as input from the stakeholders. Lastly, creating the PJM requires the industrial designer to take a long-term perspective, focusing on what can happen during consecutive use cycles.

Castor Ventures
5 Laagse Strekkar



Legend:

EoL Scenario's:
- Direct reuse
- Upgrade
- Replace
- Recycle
- Remanufacture
- Repair
- Incinerate
- Refurbish

Obsolescence type:
- Technological obsolescence
- Functional obsolescence
- Emotional obsolescence

Product use-cycle origin:
- First use-cycle
- Second use-cycle
- Third use-cycle

Part categorisation:
- High impact part
- High value part
- Key function part
- Key failure part

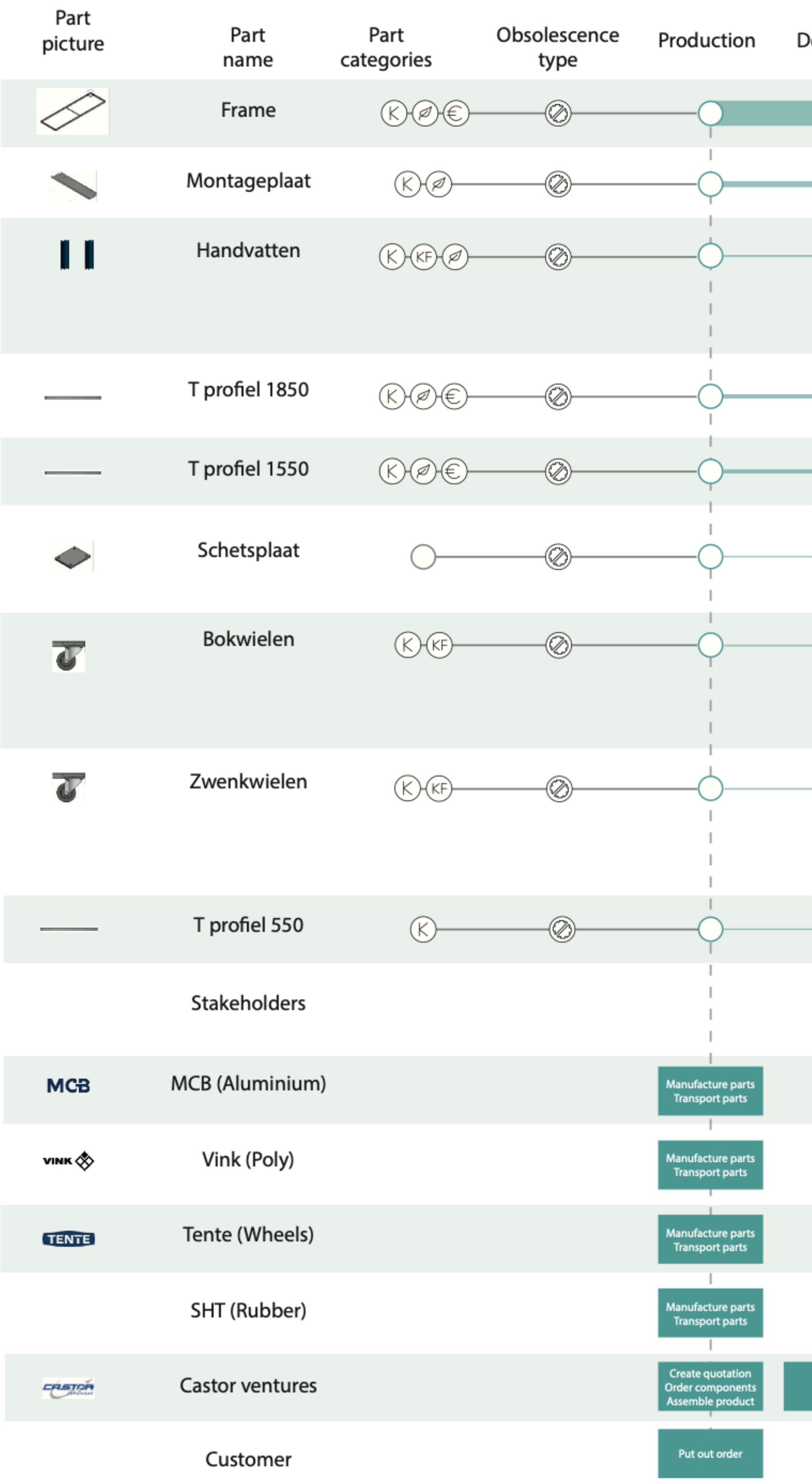
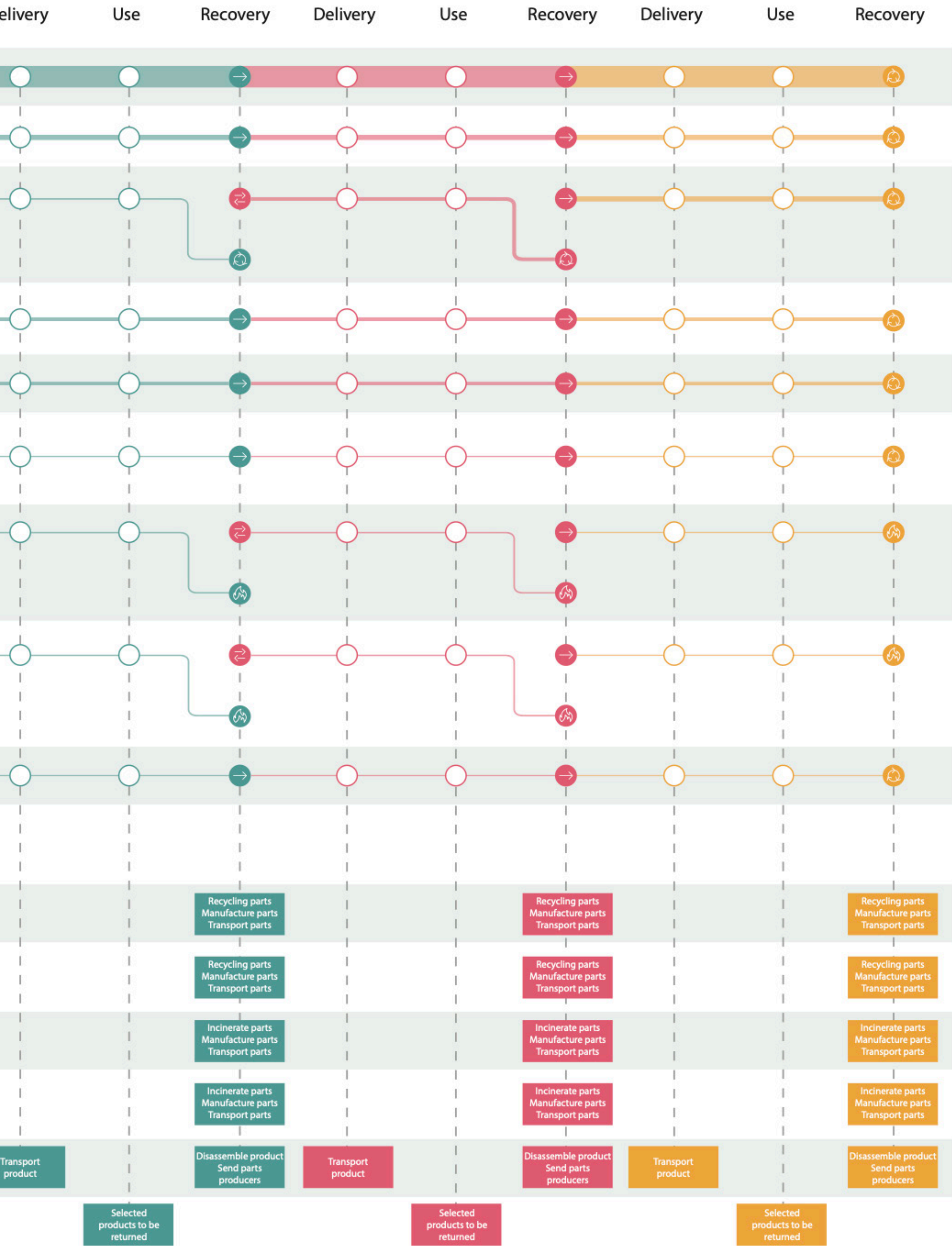


Figure 17: PJM concept 3 visualization. The upper part visualises the
and their



lifecycles of the sub-assemblies and the lower part the stakeholders
actions.

5

Testing concept 3

This chapter presents the outcome of the second usability test with Castor Ventures and Gorenje, discussions with the graduation team, and the subsequent changes to concept 3 to create the final PJM concept 4 presented in the Product Journey Map playbook. The second usability test with Castor Ventures aimed to uncover problems and discover opportunities to improve the design of the PJM. Prior to the usability test, the Castor Ventures representative selected the product and collected the relevant data: bill of materials including names and the weight of the sub-assemblies. The high-impact and high-value category calculations were prepared before the session. The usability test asked the company representative to complete all steps while speaking aloud to identify thought processes, check if the method procedure was clear, and identify obstacles. Some issues were identified during the usability test and, where possible, solved on the spot. For example, the company representative needed more information on how the product would be used throughout its lifecycle. Therefore, the lifecycle profile was introduced, a short description of how the product is used throughout its life cycle. This session, lasting one and a half hours, was recorded, and observations were noted. The goal of the second prototype test with Gorenje was to discover opportunities on how the design of the PJM could be improved, reflect on the applicability of the PJM, and discover who within Gorenje would use the PJM.

5.1 Results of the usability test

The usability test's observations and discussions with the graduation team were analyzed. The learnings formed the basis for seven changes to concept 3, resulting in concept 4 of the PJM presented in the Product Journey Map playbook (appendix V). These changes are presented in sub-chapters 5.1.1 - 5.1.7. The addition of logistics in the PJM is discussed but not implemented in concept 4.

5.1.1 Synergy improvement

The synergy of Asif (2019) is very rigid, meaning that it is very systematic and leads to one outcome. A consequence of this is that the PJM might unnecessarily replace or upgrade sub-assemblies in the case of emotional or technological obsolescence. According to Asif's synergy, if the casing of a product is identified as customer intimacy, it will undergo emotional obsolescence and therefore be replaced or upgraded at the end of the use cycle. Nevertheless, there could be various reasons why this would be suboptimal. By introducing an end-of-life scenario checklist, an extra tool is provided to help designers make the right decisions for end-of-life scenarios and check the feasibility of the end-of-life scenario. It has to be noted that this list is not exhaustive.

For all cases:

- ☐ Does your company have a program to retrieve products or sub-assemblies from the market actively?

In case of direct reuse:

- ☐ Does your company provide instructions and protocols to the relevant departments or third parties to check the quality of the to-be reused sub-assembly?
- ☐ Does the sub-assembly have a longer than average category lifespan, and is the sub-assembly design optimized for longevity?
- ☐ Does the user experience noticeable degradation of the sub-assembly, and is it likely to significantly affect product acceptance?
- ☐ Does failure increase the lifecycle cost above the replacement to prevent it would cost?
- ☐ Is the disassembly and reassembly of the sub-assembly optimized for time, cost efficiency, simplicity, and tool availability?

In case of upgrading:

- ☐ Does your company provide instructions and protocols to the relevant departments or third parties for the upgrading of the sub-assembly?
- ☐ Does the sub-assembly allow for enhancing its functionality or cosmetic condition?
- ☐ Has new technology been introduced to the market that renders the sub-assembly and the product technologically obsolete?
- ☐ Will the "user experience" worsen if the sub-assembly is not upgraded?
- ☐ Is it likely to significantly affect product acceptance?
- ☐ Does your company have the means to facilitate the upgrading of the sub-assembly?
- ☐ Is upgrading the sub-assembly optimized for time, cost efficiency, simplicity, and tool availability?

In case of replacing:

- ☐ Does your company provide instructions and protocols to the relevant departments or third parties for the replacement of the sub-assembly?
- ☐ Does the replaced sub-assembly enhance the functionality or aesthetic condition of the product?
- ☐ Does your company produce spare sub-assemblies to facilitate the replacement?
- ☐ Is the sub-assembly standardized and fit for forward or reverse compatibility?
- ☐ Is the replacement of the sub-assembly optimized for time, cost efficiency, simplicity, and tool availability?

In case of recycling:

- ☐ Does your company provide instructions and protocols to the relevant departments or third parties for the recycling of the sub-assembly?
- ☐ Are general recycling processes available for the materials in your sub-assembly?
- ☐ Does your company have the infrastructure to facilitate the recycling process?
- ☐ Does the sub-assembly fall apart into separate homogeneous or compatible material

fragments during the shredding process, like using resource-efficient joining techniques (e.g., clips, screws)?

- ☐ Which fraction of the material value, by cost price, can be recycled?
- ☐ Is recycling of the sub-assembly optimized for time, cost efficiency, simplicity, and tool availability?

In case of remanufacturing:

- ☐ Does your company provide instructions and protocols to the relevant departments or third parties for the remanufacturing of the sub-assembly?
- ☐ Does your company list what sub-assemblies make the remanufacturing operations feasible and viable?
- ☐ Does the product's design allow for returning its state to as-new product specification by fully disassembling, testing, replacing, and cleaning components resulting in a new product with a warranty?
- ☐ Which fraction of the material value, by cost price, can be remanufactured?
- ☐ Is remanufacturing of the sub-assembly optimized for time, cost efficiency, simplicity, and tool availability?

In case of sub-assembly harvesting:

- ☐ Does your company provide instructions and protocols to the relevant departments or third parties for the harvesting of the sub-assembly?
- ☐ Does your company list which sub-assemblies should be harvested?
- ☐ Is the harvesting of the sub-assemblies optimized for time, cost efficiency, simplicity, and tool availability?

These questions trigger designers to think about the company's capabilities and determine the feasibility of the end-of-life scenario. For example, if replacing a sub-assembly increases product acceptance but the company cannot facilitate this replacement, a change is necessary. The company could either change the sub-assembly or check with the current stakeholders and, if necessary, outsource the activity.

To provide designers with more information to map the extended product lifecycle, companies need to determine what requirements the product needs to fulfill at each use cycle. These requirements depend on the company's strategy. For instance, does the company want to provide as-new products each use cycle, or is it trying to access another market segment by supplying cheaper, used versions of the product. Additionally, companies could distinguish between technological, aesthetical, and/or hygienical requirements. Distinguishing between types of requirements helps companies specify the requirements from different perspectives, ensuring completeness. With this information in mind, designers can determine whether the selected End-of-Life scenarios of sub-assemblies are correct.

5.1.2 Lifecycle profile

A lifecycle profile describes how the product is used throughout its lifecycle. During the usability test, determining the lifecycle of the sub-assemblies turned out to be difficult, despite Asif's (2019) synergy between strategic disciplines, product obsolescence, and end-of-life scenarios. A product can experience many potential scenarios. For example, the Castor Ventures representative pointed out that the pushcarts come back in various repairability states. Sometimes, the pushcarts get stuck between the docking station and the truck, resulting in irreversible damage. Therefore I introduced the term product lifecycle profile. This change was implemented during the test session and immediately provided the company representative with a clear starting point:

The Castor Ventures pushcart will have two use cycles of eight years, resulting in a total life cycle of 16 years if used under normal conditions. These normal conditions were outlined by Castor Ventures as follows: the product is used twelve hours a day, seven days a week, loaded to a maximum of hundred-fifty kg, and used at a temperature no lower than -30 degrees celsius.

It could be argued that the lifecycle profile acts as the persona of the PJM, as it represents the product and facilitates, similar to the CJM (Goodwin, 2009), the understanding of the products' behavior and limitations.

5.1.3 Excluding CO2 footprint calculations

The current calculations provided a superficial and incomplete picture of the sub-assemblies' CO2 footprint. For example, the calculations do not consider energy usage during the use cycle of the product or transportation. The calculations could work for products such as Castor Ventures pushcart, which does not use any energy during its usage. Nevertheless, for a product such as Gorenje's Asko washing machine, water usage, and electricity efficiency is essential for its CO2 footprint. During the discussion of the prototype session with Castor Ventures, the company representative made a similar remark, stating that he wondered how the calculations would have worked if his product had used energy.

Additionally, a sub-assembly could contain various materials. Therefore, using the primary material to calculate the CO2 footprint over time will create an inaccurate representation. Furthermore, the current implementation of the CO2 footprint calculations removed the continuity of the product journey. An example was the implementation of the CO2 footprint calculations for reuse. According to the calculations provided by the Granta Edupack software, reusing a sub-assembly would result in negative CO2 footprint values (figure 18). Having negative CO2 footprint values felt counterintuitive, and therefore, the calculations were changed to be cumulative, meaning the CO2 footprint would only ever increase depending on the end-of-life scenario. This resulted in reused sub-assemblies having a constant line thickness, as shown in figure 8. For all the reasons mentioned above, the CO2 footprint calculations for the lifecycle were removed. Nevertheless, the CO2 footprint calculation, based on the hotspotmapping tool by Bas Flipsen (2017), will remain embedded in the high-impact category calculation.

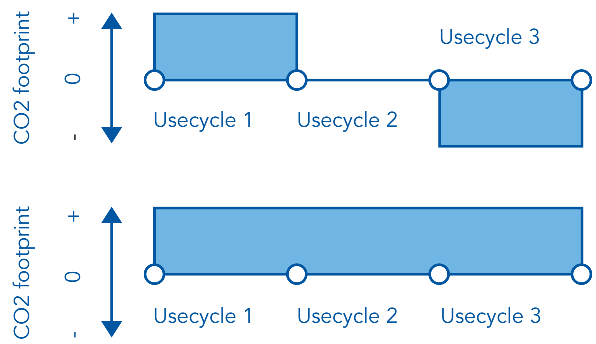


Figure 18: Difference between the non cumulative CO2 (top) footprint and cumulative CO2 footprint (bottom).

5.1.4 Sub-assembly categories

Furthermore, the sub-assembly categories underwent simplifications. The key function category seemed redundant, as sub-assemblies that are not key to the functionality do not exist, as they would not be in the product. Additionally, the key failure sub-assembly category was renamed into key replacement category, according to the definition by Bracquené et al. (2018). The definition, however, remains the same, namely: sub-assemblies prone to high failure rates. Additionally, it was observed in the test cases, and noted by the graduation team, that most high-value sub-assemblies are also high-impact sub-assemblies. For example, large sub-assemblies contain lots of material, hence having a larger CO2 footprint and higher intrinsic value. Therefore, the second simplification is the merger of the high-value and high-impact sub-assembly categories into the high-impact sub-assembly category. Hence, the final sub-assembly categories are the key replacement category and high-impact category.

5.1.5 Visualization

The visualization of PJM concept 3 can be improved by providing more timestamps in the timeline and by adding icons to every stage of the lifecycle (figure 22/23). Currently, the timeline at the top of the PJM highlights the start and end of use cycles. During the usability test with Castor Ventures, the company representative was also interested in knowing the length of the lifecycle's stages, e.g., duration of the repair and product return to the market. Additionally, Gorenje indicated that delivery times of certain sub-assemblies vary drastically, which should be taken into account when mapping the product life cycle. In PJM concept 3, the same distance between the stages is used to be able to visualize the PJM on one page. Alternatively, the distance between the stages could be proportional to their length in time, as shown in figure 19, resulting in an improved sense of time throughout the visualization. Lastly, equipping the visualization of the PJM with icons for the lifecycle's stages further improves the readability, as shown in figure 22/23.

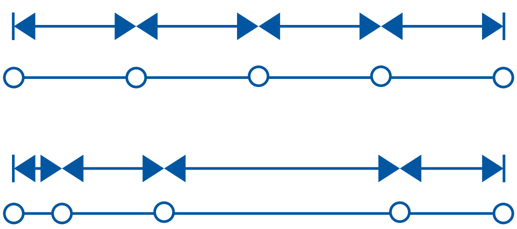


Figure 19: Equal spacing of time in a swimlane vs proportional spacing to length in time.

5.1.6 Sub-assembly harvesting End-of-Life scenario

During the second prototype session with Gorenje, it became apparent that they saw value in the PJM, especially when it came to planning and harvesting spare parts. I quote the representative of Gorenje: "we try to harvest spare parts, this type of tool is excellent for this type of project." According to the representatives of Gorenje, being able to know when spare sub-assemblies are necessary is vital to the program and repair department of Gorenje. Additionally, knowing which spare sub-assemblies can be harvested from the product is equally important. These spare sub-assemblies can be used to repair broken products but also offer the additional benefit of being economically advantageous:

- ☐ Depending on their harvesting location, these spare sub-assemblies could be closer to the repair site and lower transportation costs.
- ☐ According to the Gorenje representatives, these spare sub-assemblies will be cheaper and might incentivize clients to repair their products instead of purchasing a new product.
- ☐ The PJM could help explore buyback options from third-party dismantlers.

Therefore, the End-of-Life scenario spare sub-assembly harvesting is added to the PJM. This End-of-Life scenario has its own icon, as illustrated in figure 20, and can be applied to sub-assemblies such as the motor of the Asko professional washing machine in figure 22/23, as this sub-assembly still has one use cycle left at the end of the life cycle.

End-of-life scenario sub-assembly harvesting

Figure 20: Overview of end-of-life scenario icons

5.1.7 Bottleneck indicator

The representatives saw value in mapping bottlenecks in the Product Journey Map. The key-failure sub-assembly category is one form of a bottleneck indicator, indicating sub-assemblies with high failure rates. Nevertheless, according to the Gorenje representatives, other bottlenecks include divergent delivery times and complex logistics. The checklist presented in sub-chapter 5.1.1 might help companies identify bottlenecks. Bottleneck examples include a lack of general recycling processes available for sub-assemblies materials or the sub-assembly not being fit for forward compatability. Inspired by the comments of the Gorenje representatives: "it might be nice to mark some points where bottlenecks are in the circles," the bottleneck indicator will be placed within the circles during the non-End-of-Life stages in the sub-assemblies lifecycle, see figure 21. If an End-of-Life scenario poses a bottleneck, the icon is placed in the right corner of the End-of-Life scenario icon, see figure 21. The bottleneck indicator highlights potential pain points that have been identified during the creation of the PJM. For example, a bottleneck during a "use stage" might be high failure rates. Potential bottlenecks during the transport stage include it being expensive, slow, or even impractical due to size. An additional feature to be tested in the future could be the integration of a bottleneck swimlane. In the bottleneck swimlane, users can further detail the content of the bottleneck.

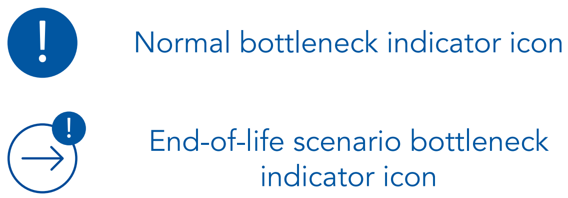


Figure 21: Overview of bottleneck indicator icons

5.1.8 Logistics in the Product Journey Map

During the prototype session, the representatives of Gorenje stressed the importance of transportation and logistics for their LCA calculations. Their LCA has two important aspects: the material and transportation sides. The Product Journey Map already has an category for key-impact sub-assemblies. However, it did not provide insight into the logistics of the sub-assemblies. In order to incorporate logistics into the Product Journey Map, the distances could be integrated into the sub-assemblies swimlanes. Integrating logistics into the PJM could help the program and repair department of Gorenje with spare sub-assembly planning and the creation of the LCA. Testing this feature could be one of the next steps in the development of the PJM.

5.2 Evaluation of PJM requirements

In sub-chapter 1.4, four requirements were introduced to test the PJM. These requirements will be evaluated separately in the next paragraphs.

Firstly, it was stated that the PJM should provide industrial designers with a systematic structure to create a lifecycle for a product. This requirement was met. The PJM is made in an isolated modeling context and is facilitated by defining the lifecycle stages and assigning scenarios to the sub-assemblies of the product. The end-of-life scenarios can be determined based on the strategic disciplines and the obsolescence profiles. After creating the PJM, learnings can be drawn concerning design adjustments in a participatory workshop setting. Through clustering parts and forming sub-assemblies, the PJM can differentiate between journeys of different sub-assemblies in one visualization. Asif (2019) pointed out that not all sub-assemblies are likely to have the same life expectancy. The PJM can help conceptualize different journeys for the product through the mapping of its sub-assemblies.

Secondly, it was stated that the PJM should help industrial designers communicate the product's journey by visualizing the product's life cycle in one illustration. This requirement was also met. The visualization is divided by the line of activity. Above the line, the sub-assembly lifecycles are presented. Below the line, the stakeholders and their roles in the circular system are presented. The product's lifecycle is visualized clearly and coherently by using swimlanes on the horizontal axis. Gorenje company representatives stated that "the PJM is very visual, which is interesting when you want to explain to someone where the sub-assemblies are and for repairability and upgradability issues this could also be used to optimize these results."

Thirdly, it was stated that the PJM should help industrial designers determine organizational actions at each stage in the product's lifecycle. This requirement was met because the relevant stakeholders and their roles in the circular system can be identified for each stage in the lifecycle. By adding the stakeholders, a company can generate an overview of all parties involved and see potential gaps that require additional or new parties to join or identify which stakeholders could/should be changed. The representatives from Gorenje provided a clear example: In Denmark, most of their sales are B2B, meaning that if they wanted to set up their Asko professional washing machine pay-per-use model, they would not need any additional stakeholders. Nevertheless, in the Netherlands, this was not possible since Atag mainly focuses on B2C. Hence an additional party was required, namely Homie. I believe that mapping out the product's lifecycle using the PJM could have helped Gorenje in this case during the determination of these stakeholders and their actions per country.

The fourth requirement of the PJM stated that the PJM helps industrial designers enhance value capture from a product by improving the effectiveness and efficiency of each product usecycle. Here improving the effectiveness is defined as the degree to which the PJM improves the production of the desired result; success. Improving efficiency is defined as improving the outcome with the least wasted time, effort, and resources. The PJM assists designers to extend the lifecycle of a product and map the expected behavior, developing a sensible starting point to determine the necessary stakeholders and their subsequent actions, assisting designers in further narrowing and closing the loop. In this case, the desired result of PJM's user is a circular lifecycle, which the PJM facilitates to create, thereby improving the effectiveness of each use cycle. Nevertheless, according to the definition, it does not necessarily improve efficiency besides the End-of-Life scenario checklist questions. However, as previously mentioned, it can function as the input for an LCA or other methodologies that may improve efficiency.

The last requirement of the PJM stated that it should help industrial designers determine the environmental footprint of the product's lifecycle. In concept 3 the requirement was met. However, for concept 4, it was decided to remove the CO2 footprint calculations from the PJM and the requirement.

Finally, the changes and insights, with exception of the logistics, discussed in this chapter have been implemented into the final concept 4, which is presented in the Product Journey Map playbook, which can be found in Appendix V. The PJM playbook provides a complete overview and describes concept 4 using the five elements of method content as described by Daalhuizen including the End-of-life checklist as well as the interpretation of the visualization.

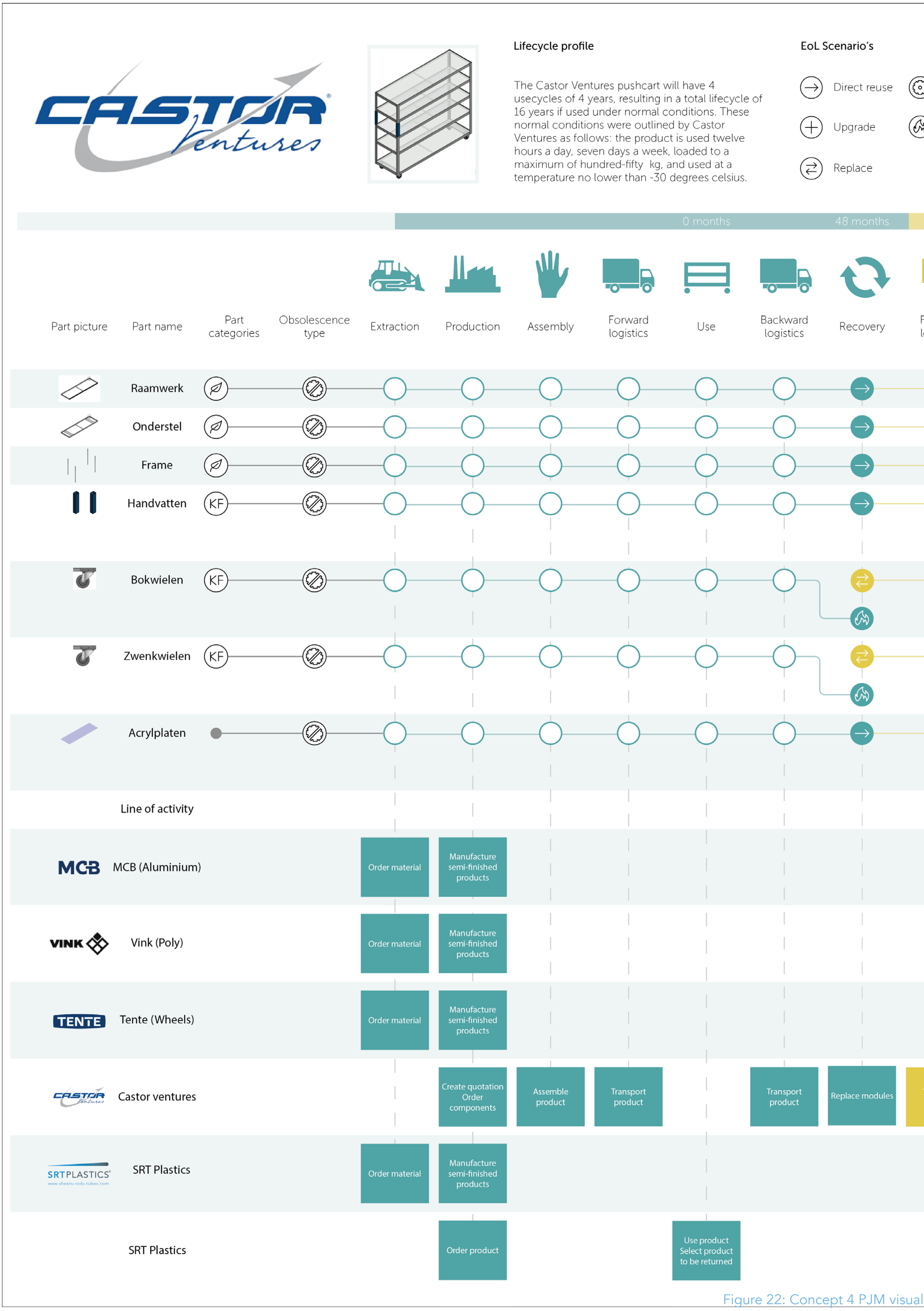
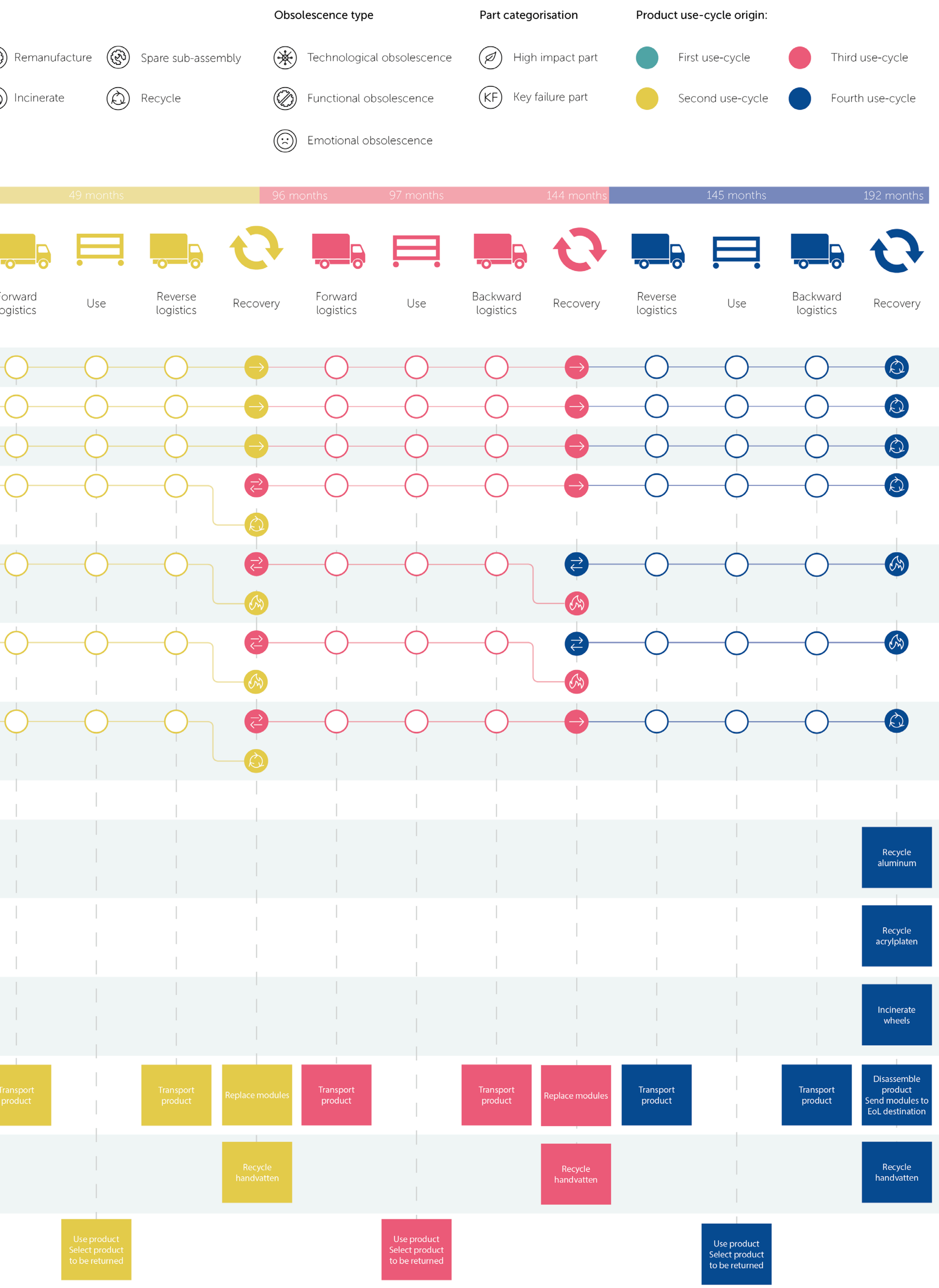


Figure 22: Concept 4 PJM visual



ization Castor Ventures Strekkar.

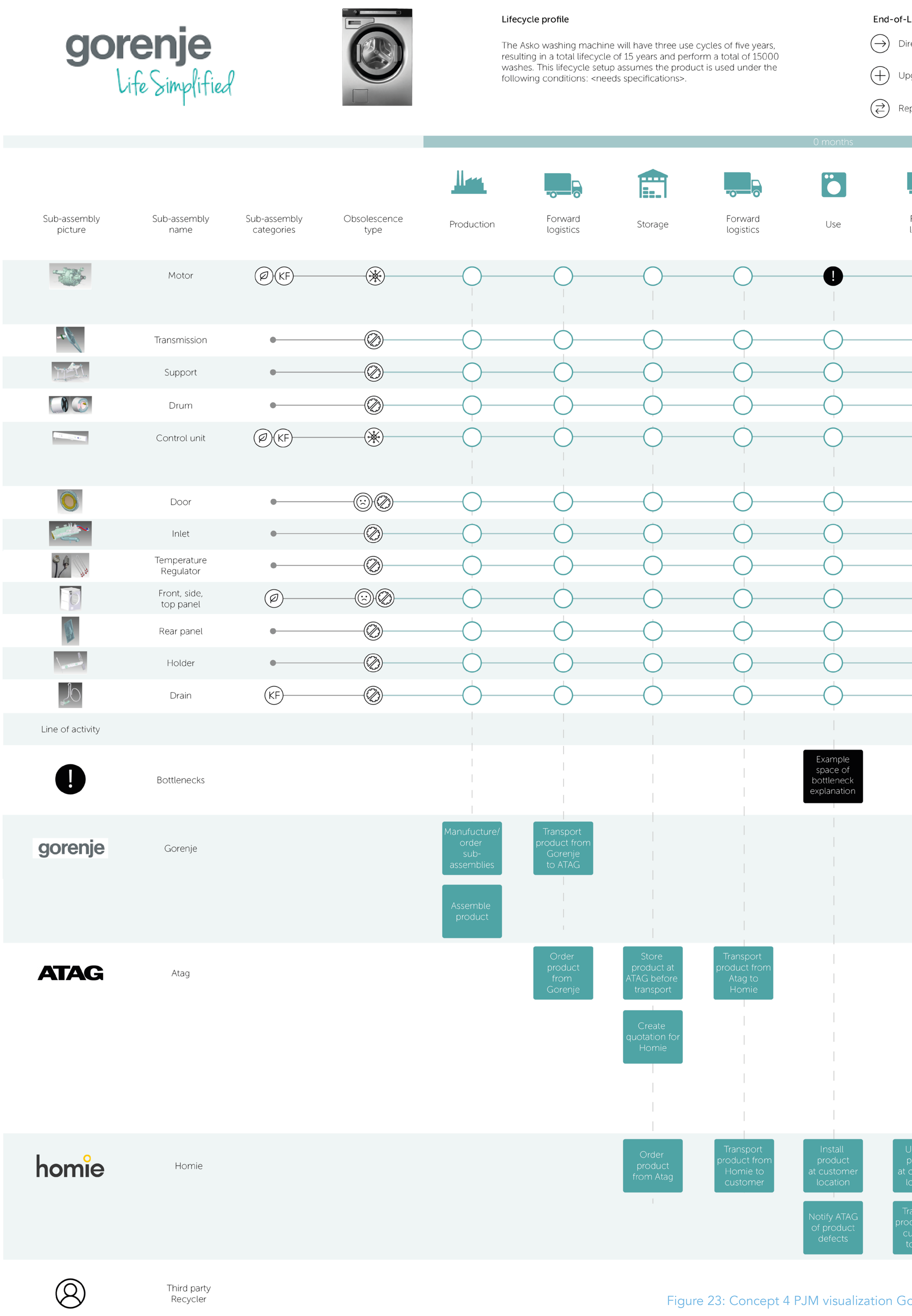
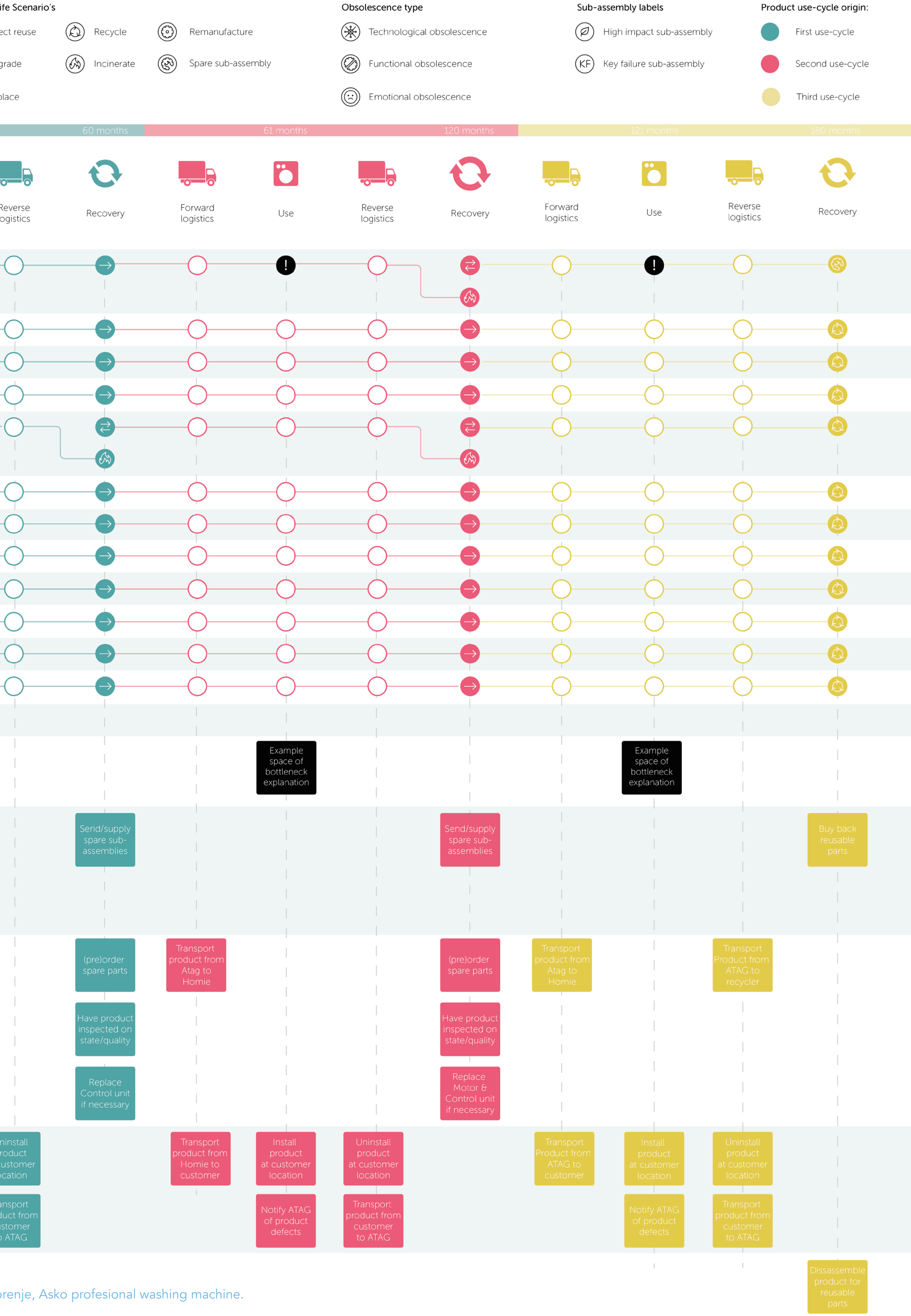


Figure 23: Concept 4 PJM visualization Go



renje, Asko profesional washing machine.

6

Going full circle

At the end of this project, it is time to reflect and go full circle. This chapter will deal with my reflections on the PJM, my personal learnings (6.1), and determine if I have achieved my personal goals (6.2).

6.1 The product journey map

The Product Journey Map is a novel design methodology with the potential of being valuable to industrial designers and design teams within companies. Gorenje and Castor Ventures have indicated that they see potential in the PJM with multiple applications such as the planning of spare sub-assemblies, redesigning sub-assemblies, and creating input for their LCA calculations and as a communication tool. Gorenje indicated that the PJM could be used by various departments such as the Research & Development department, program department, and research department. Additionally, the Gorenje representatives also stated that they are now adopting a sustainability department, which according to the representatives could also use the methodology to identify new opportunities.

The PJM could benefit from further testing and development, especially in-field use. For example, the graduation team indicated that the terms strategic disciplines and product obsolescence types might be difficult terms and potentially lead to confusion. Further user testing verify whether these terms are indeed confusing and have to be replaced. The PJM has now been tested with companies from the white goods industry and from the metal industriy. Therefore, the PJM could benefit from testing products from other sectors as these products may require a different focus area. Moreover, both products are sold in a B2B market and therefore to further develop the PJM it has to be tested on B2C products.

As previously mentioned, the checklist presented in sub-chapter 5.1.1 provides the industrial designers with a starting point to reflect upon the chosen End-of-Life scenario, but is not exhaustive. Validating the checklist with specialists might further improve and generate additional questions to guide the industrial designer even better. Perhaps, in the long term it might even provide a complete checklist.

From the previous learnings and the reflection above, it becomes clear that the PJM requires further development. With this graduation project, I hope to have laid a foundation from which other designers, academics, and industry specialists can further improve the Product Journey Map to become a full-fledged design methodology.

6.2 Reflecting on my goals

My first goal was to create and test an intuitive design mapping methodology. Although I am confindent in saying that I have reached this goal, as both Castor Ventures and Gorenje have expressed their interest in the PJM, I am aware that to completely verify this, I would have to perform additional user testing.

The second goal was to gain more experience in designing and preparing prototype sessions. The first tests performed with Gorenje and Castor ventures were difficult as I was still exploring the goal and structure of the Product Journey Map. I could have setup these prototype sessions more effectively if I had made exploring the goal and structure of the PJM the focal point. Instead, I was more focused on presenting a methodology rather than brainstorming with Castor Ventures and Gorenje on how to further develop the PJM, resulting in a loss of information on how to move forward. Having learned from this mistake, the second prototype sessions were designed differently, emphasizing the fact that the PJM is a methodology in development, resulting in more constructive and useful feedback.

The last goal I set for myself was to improve on my academic writing. Challenging parts of this project included expressing my ideas, finding the appropriate sources, and finding a good format for this thesis. It took a lot of effort to (re)structure my text, but it has taught me how to channel my thoughts and findings, the importance of rewriting content, and ultimately resulted in an improvement of my academic writing. Through this process I have become a better critical thinker reflecting on what the proper conclusions might be.

6.3 Growing as a designer

Despite being confident about the outcome of this project, methodology designing was not one of my initial strengths. It is complicated and requires a lot of knowledge and expertise to make good judgment calls on what is supposed to be incorporated and what not.

Finally, creating a methodology that will help companies transition towards a circular economy has been rewarding. It has given me the opportunity to combine my learnings from the IDE bachelor program, SPD master program and TiSD annotation program. In the future, I hope to apply the knowledge gained from this graduation project and creating the PJM in a professional setting, to guide companies towards a circular economy and sustainable future.

7

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This section of the report contains all textual citations and visual citations from this graduation report.

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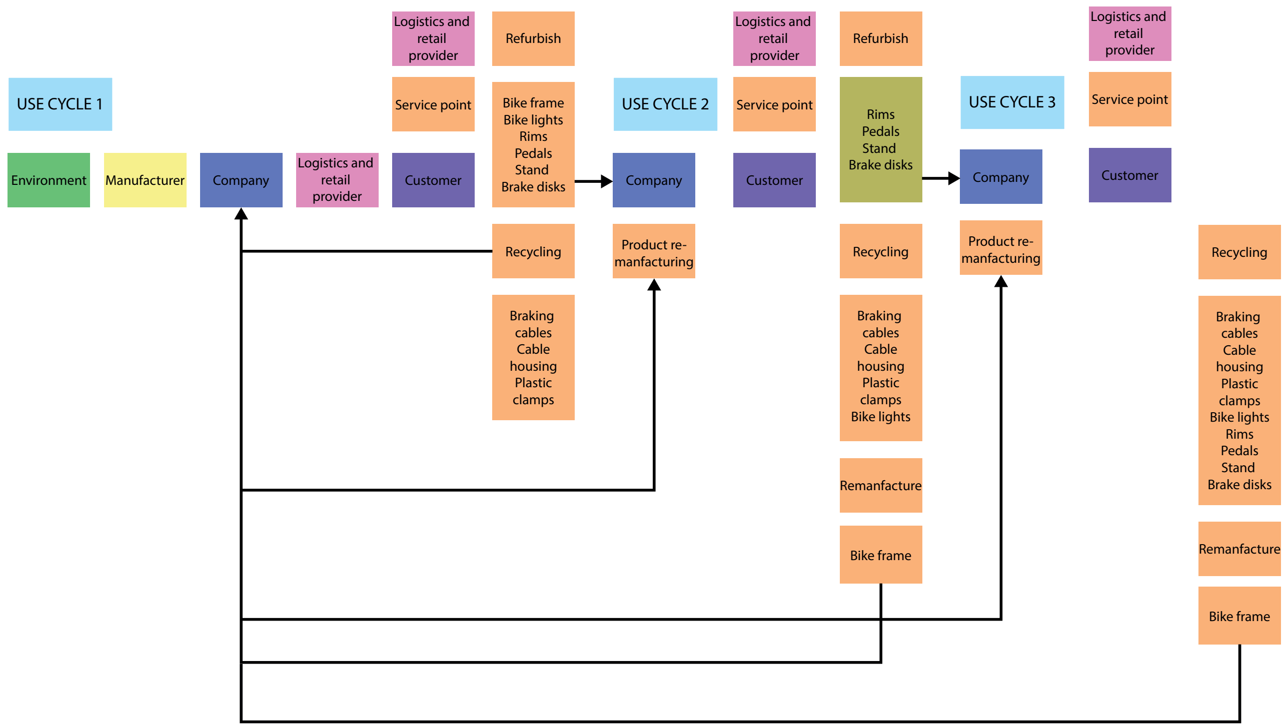
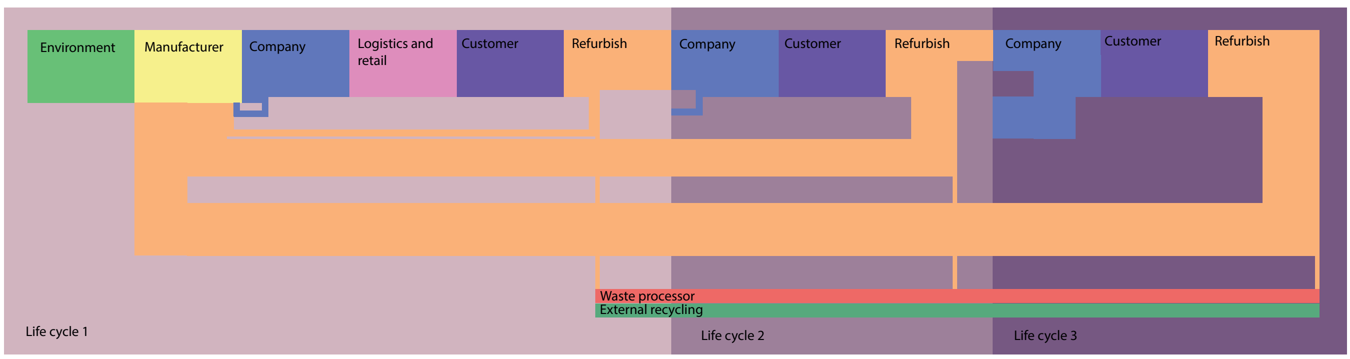
8

Appendixes

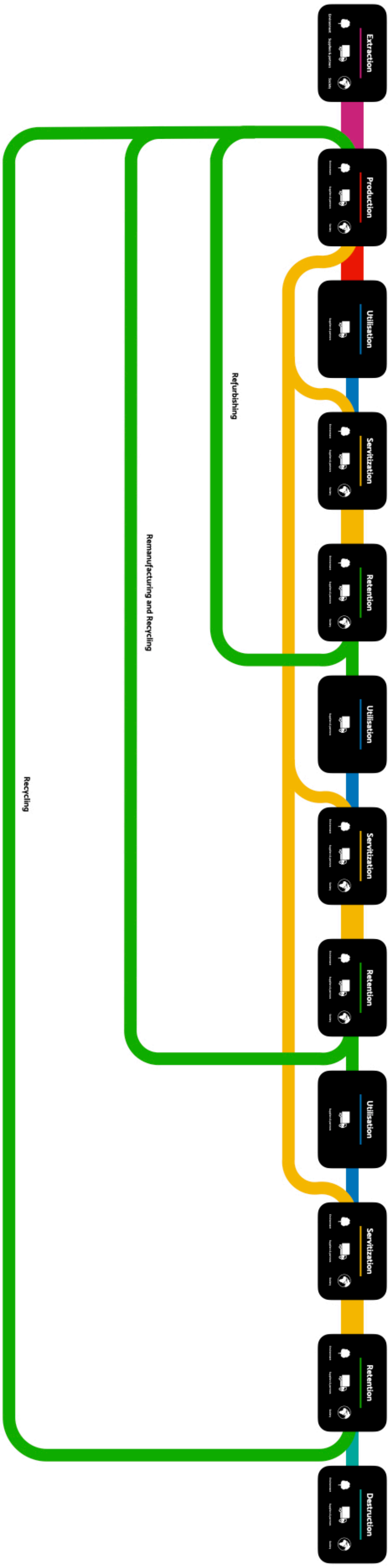
This section of the report contains the appendix of this graduation report.

8.1 Appendix I: Visual exploration 1

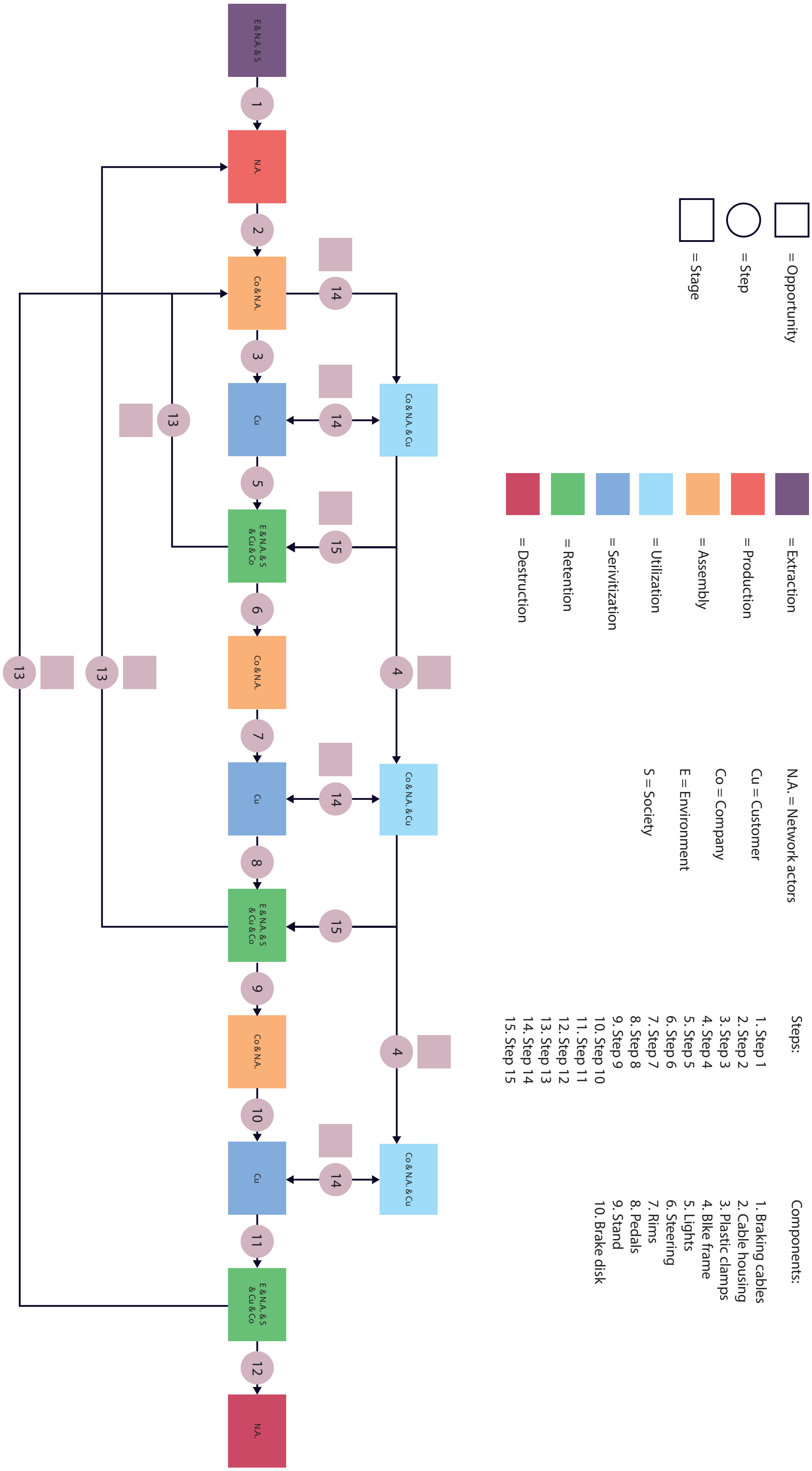




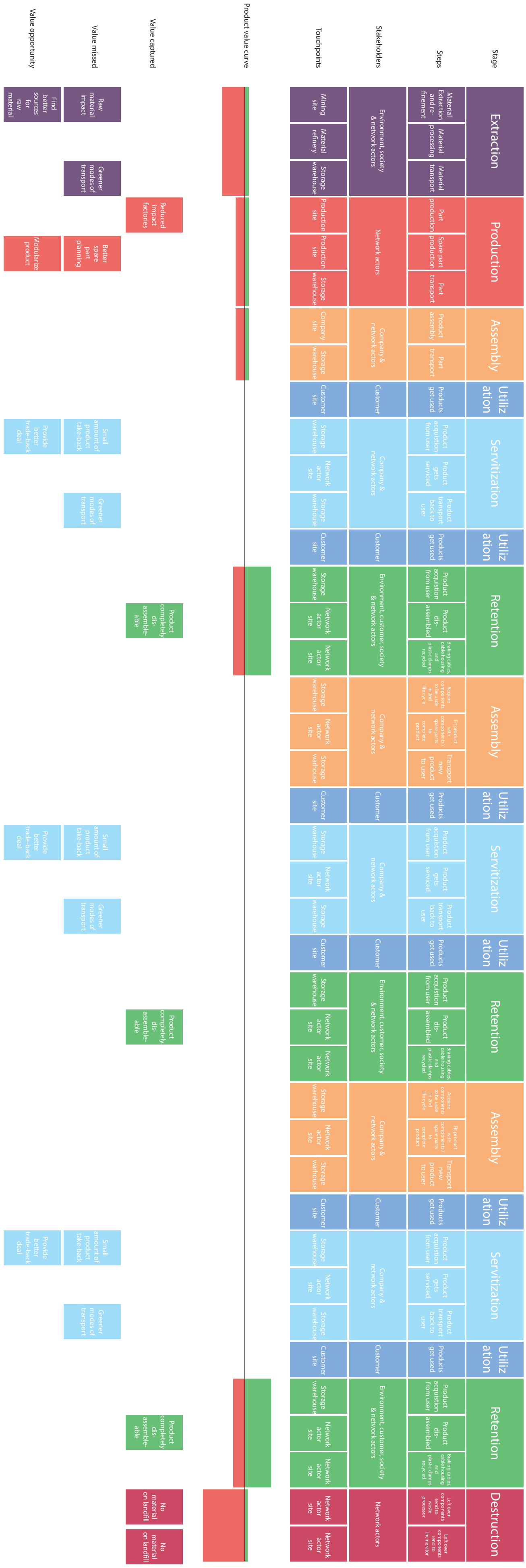
8.2 Appendix 2: Visual exploration 2



8.3 Appendix 3: Visual exploration 3



8.4 Appendix 4: Visual exploration 4



Product Journey Map

Playbook

Master thesis
Finn Kooijman

Foreword

The Product Journey Map playbook is the final result of my graduation project as part of the Strategic Product Design master's program at the Technical University Delft. The project was performed in collaboration with the TU Delft ReCiPSS team and the involved testing companies Castor Ventures and Gorenje. This project aimed to develop a design methodology to help industrial designers identify opportunities to slow down and/or narrow down and/or close resource loops by systematically mapping the products' lifecycles. Having gone through the Industrial Design Engineering Bachelor, Strategic Product Design master, and the Technology in Sustainable Development annotation program, this graduation project allowed me to combine the interests that I developed throughout my academic career. During this graduation project, I had the privilege to explore my interests with an amazing and passionate supervisory team and testing team. Therefore, I want to thank Professor Dr. Ir. Conny Bakker & Dr. Ir. Charlotte Kobus, Ph.D. candidate Ir. Nina Boorsma, Robin A. van der Torre of Castor Ventures and Dr. Aleš Mihelič & Simon Kotnik from Gorenje for all their help and support throughout this project.

Chair
Prof. dr. ir. Bakker, C.A.

Mentor
Dr. ir. Kobus, C.B.A

2nd Mentor
Ir. Boorsma, N.E.

Castor Ventures
Van der Torre, R.A.

Gorenje
Dr. Mihelič, A.

Gorenje
Kotnik, S.

Structure

The playbook has been structured according to the 5 elements of method content by Daalhuizen. He advocates his five key elements to describe a design methodology's content being: the method rationale, the method framing, the method goal, the method procedure, and the method mindset. Each individual element represents a different aspect of the design methodology:

- ☐ The method rational section of the playbook will explain why the method's goal is relevant and meaningful.
- ☐ The method framing section of the playbook provides information on the context by describing how industrial designers and companies can appropriately use the method.
- ☐ The method goal section of the playbook outlines the method's goal it tries to achieve.
- ☐ In turn, the method procedure explains how the method contributes to reaching the method's goal.
- ☐ Lastly, the method mindset describes the users' beliefs and prerequisite knowledge needed in order to use the method properly and successfully.

Photo: Marjolein van der Veldt

Rationale

At this time, our linear economy urgently needs to transform toward a circular, less wasteful system to restrain the global environmental footprint of the products we use. There are three approaches to moving toward a circular economy: slowing resource loops, closing resource loops, and narrowing resource loops. Firstly, slowing resource loops extends a product's lifecycle through maintenance and repair, thereby extending the product's utilization period. Secondly, closing resource loops, through, for example, recycling, closes the loop between post-use and production, resulting in a circular flow of using fewer resources per product. Thirdly, narrowing resource loops refers to using fewer resources per product.

The PJM provides designers with the tools to extend a product's lifecycle and map the expected behavior, slowing down the material loop and putting the product center stage. Mapping a products' lifecycle is a complex endeavor. Therefore, the PJM analyses not the product as a whole but its sub-assemblies. Companies can use the PJM to close the material loop by identifying sub-assemblies that are not yet recycled. Moreover, the PJM links the stages in the products lifecycle to the actions performed by stakeholders. This way, designers can analyze the effects of changes made on the stakeholder(s) side and vice versa. Lastly, It can serve as input for other methodologies such as the life cycle assessment. These methodologies require product life cycle scenarios as input for their calculations. However, designers cannot use these methodologies to generate these scenarios that form the basis for their calculations.

Photo: Tom Fisk

Framing

The Product Journey Map is a planned visual rendering of the product's expected life cycle and underlying structure. It extends the product's life cycle, slowing down the material loop, and identifies opportunities to further close the material loop. The Product Journey Map is data-driven, meaning it requires industrial designers to have the following information:

- ☐ The bill of materials
- ☐ Sub-assembly names
- ☐ Sub-assembly primary material
- ☐ Sub-assembly weights
- ☐ Failure rates
- ☐ Environmental information on materials

Due to the necessary information to use the Product Journey Map, it is advised to use it in the later stages of the development cycle. As identified by Gorenje, designers would apply the Product Journey Map during or just before creating the product's life cycle assessments (LCA). During this stage, it can assist in conceptualizing ideal circular scenarios for products, and, at later stages of design, it helps substantiate decision-making for detailing the design directions.

Goal

The Product Journey Map provides insight into the flow of a product and its sub-assemblies throughout multiple usecycles by mapping different scenarios and stakeholders' roles. It helps create a viable circular system to increase resource efficiency and decrease environmental impact, slowing down, closing, and narrowing the resource loop.


Photo: Pixabay

Procedure

In the following steps, describe the method procedure. Steps 1-9 concern generating input, and steps 10-13 visualize the input.

Step 1: Sub-assembly identification

This step identifies the sub-assemblies of the product. Sub-assemblies are part clusters that are easy to disassemble from a product, have limited connectors to the other components, and often support the same product function. The parts within these clusters tend to have a comparable life expectancy. The product architecture typically prescribes what the subassemblies of a product are. Note down the following information for the sub-assemblies in a table format (see figure 2):

- ☐ Name the sub-assemblies
- ☐ Determine the sub-assembly weights
- ☐ Specify the primary material(s) used

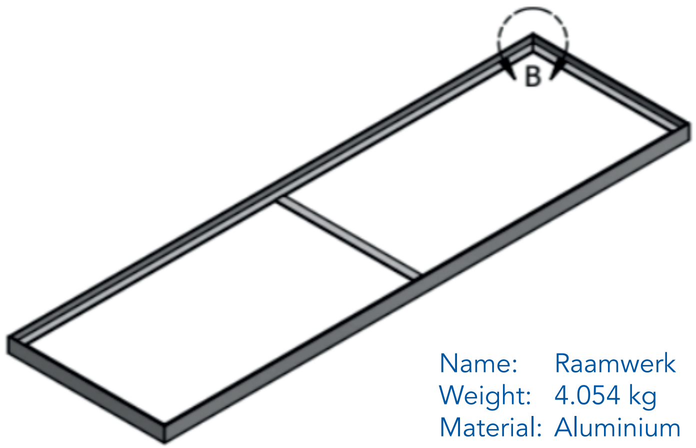


Figure 1: Example sub-assembly Castor Ventures.

Step 2: Creating the life cycle profile

This step creates the lifecycle profile of a product. A lifecycle profile describes how the product is used throughout its lifecycle. When creating the Product Journey Map, certain assumptions on the use of the product need to be made, as many potential use scenarios could occur. The lifecycle profile should follow the formula as described below:

[Product name] will undergo [number] use cycles of [number] years, resulting in a total lifecycle of [number] years if used under the following conditions: [insert conditions].

An example of life cycle profile for the Castor Ventures pushcart is as follows:

The Castor Ventures pushcart will have two use cycles of eight years, resulting in a total life cycle of 16 years if used under normal conditions. These normal conditions were outlined by Castor Ventures as follows: the product is used twelve hours a day, seven days a week, loaded to a maximum of hundred-fifty kg, and used at a temperature no lower than -30 degrees celsius.

Sub-assembly number	Sub-assembly name	Sub-assembly primary material	Sub-assembly weight	Key failure sub-assembly	High impact sub-assembly	Strategic discipline	Product obsolescence	End of life scenario use cycle 1	End of life scenario use cycle 2	End of life scenario use cycle 3
1										
2										
3										
4										
5										

Figure 2: Empty example of the PJM information table.

Sub-assembly number	Sub-assembly name	Sub-assembly primary material	Sub-assembly weight	Sub-assembly impact	Sub-assembly value
1	Sub-assembly A	Material A	X kg	100 CO2 kg/kg	€ 100
2	Sub-assembly B	Material B	Y kg	90 CO2 kg/kg	€ 90
3	Sub-assembly C	Material C	Z kg	80 CO2 kg/kg	€ 80
4	Sub-assembly D	Material D	C kg	70 CO2 kg/kg	€ 70
5	Sub-assembly E	Material E	V kg	60 CO2 kg/kg	€ 60

Figure 3: Highlighting the highest CO2 footprint, 80th percentile (yellow) and 90th percentile (red)

Step 3: Defining usecycle requirements

Define the state in which the products need to be at the beginning of each use cycle, e.g., new-state or used-state. Subsequently, define the requirements of the product at the beginning of each use cycle with regards to, for example, aesthetics and technology.

Step 4: Identify high-impact sub-assemblies

High impact sub-assemblies are sub-assemblies with a high CO_2 footprint. To identify high-impact sub-assemblies, the following calculations can be used. Please note that the calculation is an indication rather than an exact number:

Impact sub-assembly = embodied CO_2 material (CO_2/kg) * weight (kg)

If sub-assembly A has a material CO_2 footprint of 13.05 CO_2/kg, and has a weight of 4kg:

Impact sub-assembly = 52.9 CO_2/kg

Sub-assemblies are flagged when the sub-assembly has the highest CO_2 footprint value, where the 80th percentile colors yellow and the 90th percentile colors red. The high-impact sub-assemblies are visualized in the PJM with an icon (figure 3) (figure 4).

Step 5: Identify the key replacement sub-assemblies

Key replacement sub-assemblies are defined as sub-assemblies with a high-replacement frequency and can be inferred from field data. Sub-assemblies categorized as key failure sub-assemblies often include moving sub-assemblies and sub-assemblies that have to endure heavy loads. An icon that visualizes this category in the PJM can serve as an indicator or starting point in the active approach of this tobe PJM (figure 4)

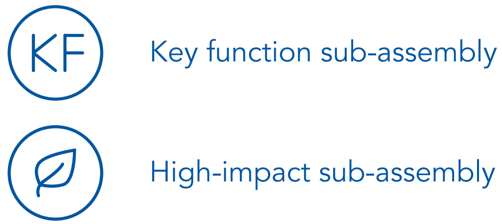


Figure 4: Icons sub-assembly categorizations

Step 6: Determine the obsolescence types

This step identifies the obsolescence type of the sub-assemblies. First, define the strategic discipline of the sub-assembly. When companies design sub-assemblies for operational excellence, they design them for longevity, meaning the sub-assembly will function for as long as possible. Hence sub-assemblies designed for operational excellence will most likely undergo functional obsolescence. If companies design sub-assemblies for customer intimacy, they are designed to satisfy the users' desire for newness or overcome a lack of attachment to the product. Hence sub-assemblies designed for customer intimacy will most likely undergo emotional obsolescence. Sub-assemblies designed for technological leadership are constantly at the state-of-the-art level. The introduction of new or upgraded versions of the sub-assembly is frequent. These new versions are solutions to the problems the former sub-assembly has previously solved. Therefore, sub-assemblies designed for technological leadership will most likely undergo technological obsolescence.

Step 7: Determine the End-of-Life scenario

Assign End-of-Life options to the sub-assemblies. The following rules of thumb can be followed: (1) Sub-assemblies that are prone to face technological obsolescence are candidates for upgrading operations at the end of predefined lifecycles; (2) Sub-assemblies that are prone to emotional obsolescence need to be replaced with aesthetically different ones or upgraded to give a completely new look; (3) Sub-assemblies prone to face functional obsolescence are candidates for reuse. (4) Functional obsolescence tends to happen later than technological and emotional obsolescence. If product sub-assemblies are replaced, specify their EoL scenario; will they undergo recycling, remanufacturing, or combustion (figure 6)?

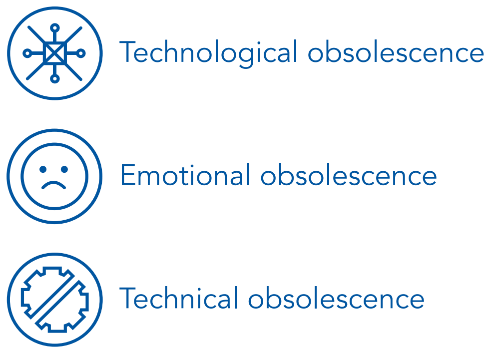


Figure 5: Icons for obsolescence types

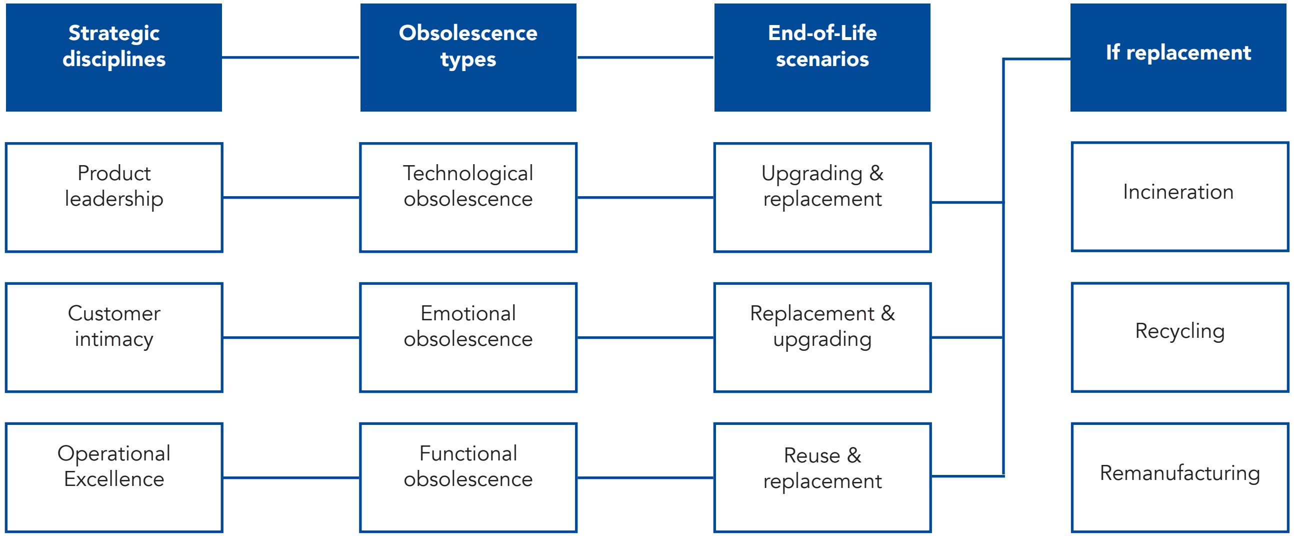


Figure 6: Overview of the synergy between strategic disciplines, obsolescence types, and end-of-life scenarios.

Step 8: End of life scenario checklist

The End-of-Life scenario checklist is an extra tool to help designers make the right decisions on end-of-life scenarios and check the feasibility. It has to be noted that this list is not exhaustive. Firstly, it is a requirement that the company has a program to retrieve the products or sub-assemblies from the market.

→ In case of direct reuse:

- ☐ Does your company provide instructions and protocols to the relevant departments or third parties to check the quality of the to-be reused sub-assembly?
- ☐ Does the sub-assembly have a longer than average category lifespan, and is the sub-assembly design optimized for longevity?

- ☐ Does the user experience noticeable degradation of the sub-assembly, and is it likely to significantly affect product acceptance?
- ☐ Does failure increase the lifecycle cost above the replacement to prevent it would cost?
- ☐ Is the disassembly and reassembly of the sub-assembly optimized for time, cost efficiency, simplicity, and tool availability?

⊕ In case of upgrading:

- ☐ Does your company provide instructions and protocols to the relevant departments or third parties for the upgrading of the sub-assembly?
- ☐ Does the sub-assembly allow for enhancing its functionality or cosmetic condition?
- ☐ Has new technology been introduced to the market that renders the sub-assembly and the product technologically obsolete?
- ☐ Will the user experience worsen if the sub-assembly is not upgraded?
- ☐ Is it likely to significantly affect product acceptance?
- ☐ Does your company have the means to facilitate the upgrading of the sub-assembly?
- ☐ Is the upgrading of the sub-assembly optimized for time, cost efficiency, simplicity, and tool availability?

⇄ In case of replacing:

- ☐ Does your company provide instructions and protocols to the relevant departments or third parties for the replacement of the sub-assembly?
- ☐ Does the replaced sub-assembly enhance the functionality or aesthetic condition of the product?
- ☐ Does your company produce spare sub-assemblies to facilitate the replacement?
- ☐ Is the sub-assembly standardized and fit for forward or reverse compatibility?
- ☐ Is the replacement of the sub-assembly optimized for time, cost efficiency, simplicity, and tool availability?

In case of recycling:

- ☐ Does your company provide instructions and protocols to the relevant departments or third parties for the recycling of the sub-assembly?
- ☐ Are general recycling processes available for the materials in the sub-assembly?
- ☐ Does your company have the infrastructure to facilitate the recycling process?
- ☐ Does the sub-assembly fall apart into separate homogeneous or compatible material fragments during the shredding process, like using resource-efficient joining techniques (e.g., clips, screws)?
- ☐ Which fraction of the material value, by cost price, can be recycled?
- ☐ Is the recycling of the sub-assembly optimized for time, cost efficiency, simplicity, and tool availability?

In case of remanufacturing:

- ☐ Does your company provide instructions and protocols to the relevant departments or third parties for the remanufacturing of the sub-assembly?
- ☐ Does your company list what sub-assemblies make the remanufacturing operations feasible and viable?
- ☐ Does the product's design allow for returning its state to as-new product specification by fully disassembling, testing, replacing, and cleaning components to result in a new product with a warranty?
- ☐ Which fraction of the material value, by cost price, can be remanufactured?
- ☐ Is the remanufacturing of the sub-assembly optimized for time, cost efficiency, simplicity, and tool availability?

In case of sub-assembly harvesting:

- ☐ Does your company provide instructions and protocols to the relevant departments or third parties for the harvesting of the sub-assembly?
- ☐ Does your company list which sub-

assemblies should be harvested?

- ☐ Is the harvesting of the sub-assemblies optimized for time, cost efficiency, simplicity, and tool availability?

Step 9: Determine use cycles

Determine how many usecycles each sub-assembly will last using the information generated in the previous steps. For example, sub-assemblies as key failure sub-assemblies or prone to emotional obsolescence will likely need replacement first. On the other hand, sub-assemblies prone to functional obsolescence will last more usecycles.

Step 10: Define the product life cycle stages

Using the information from the previous steps, create a horizontal timeline and define the product life cycle stages, e.g. production, transportation and recovery, indicating where in time these activities will take place.

Step 11: Creating swimlane visualization

Create a swimlane for each sub-assembly (figure 8). At the beginning of each swimlane, indicate the sub-assembly categories as determined in step 4. Place the icons for the EoL scenarios, shown in figure X, at the appropriate stages. If a sub-assembly is replaced, the timeline needs to kink downwards, indicating the placement of a new sub-assembly (figure 8).

Step 12: Indicating bottlenecks

The bottleneck indicator indicates potential pain points that have been identified during the creation of the PJM. A bottleneck in the use phase might be high failure rates. Additionally, in the transport phase bottlenecks include the transport being expensive, slow or even impractical due to product dimensions. Place the bottleneck icon at the appropriate stage in the sub-assemblies lifecycle. In the bottleneck lane, provide a short description of the bottleneck (figure 9).

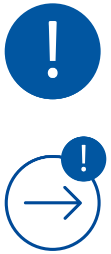


Figure 7: Overview of bottleneck indicator icons.

Step 13: Assigning stakeholder roles

For each stage, on the same vertical line, write down the actions required by the stakeholders in a verb-noun combination. Find the stakeholders needed to complete the actions. At the bottom of the PJM, create a swimlane for each identified stakeholder, order the activities appropriately and place the activities in the right order (figure 9).

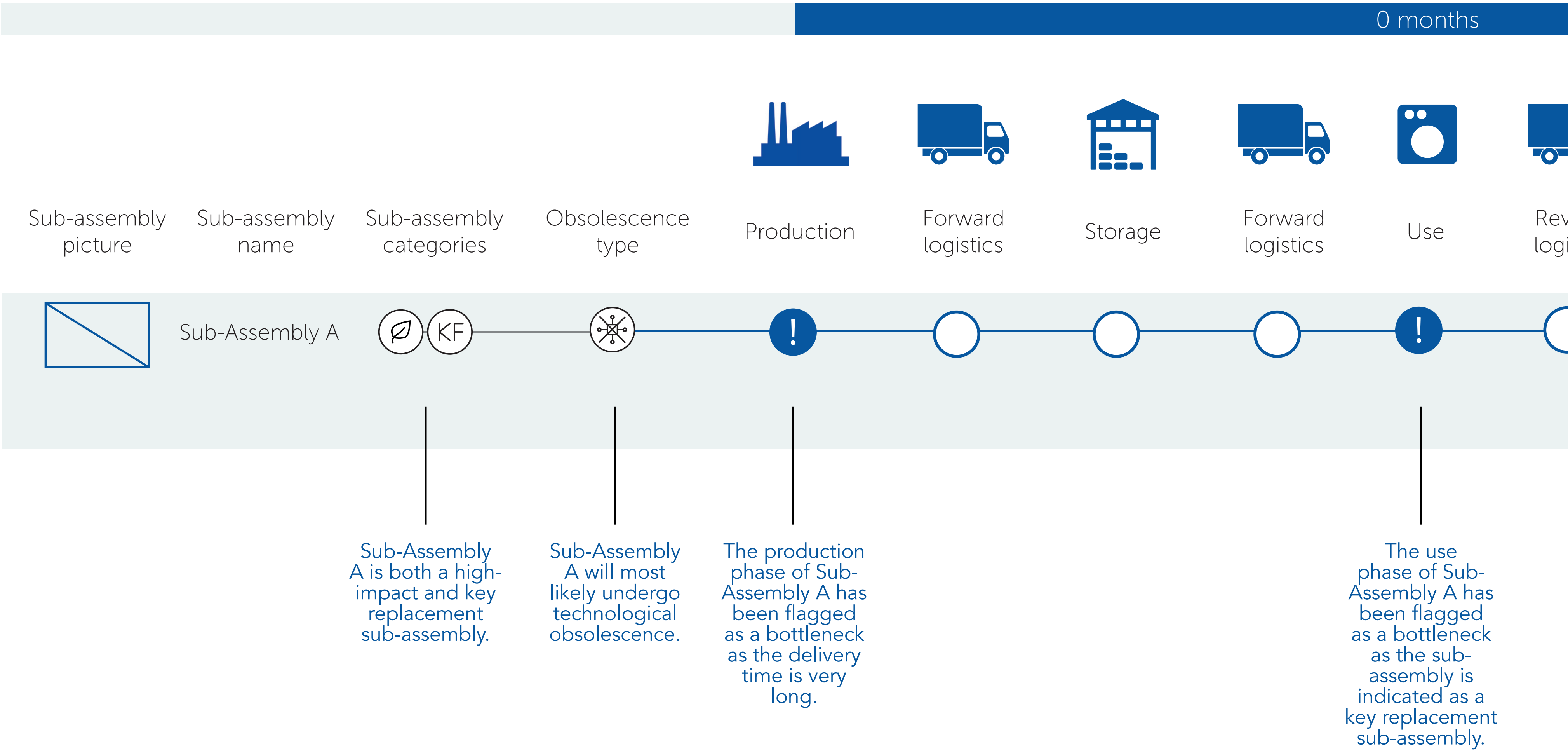
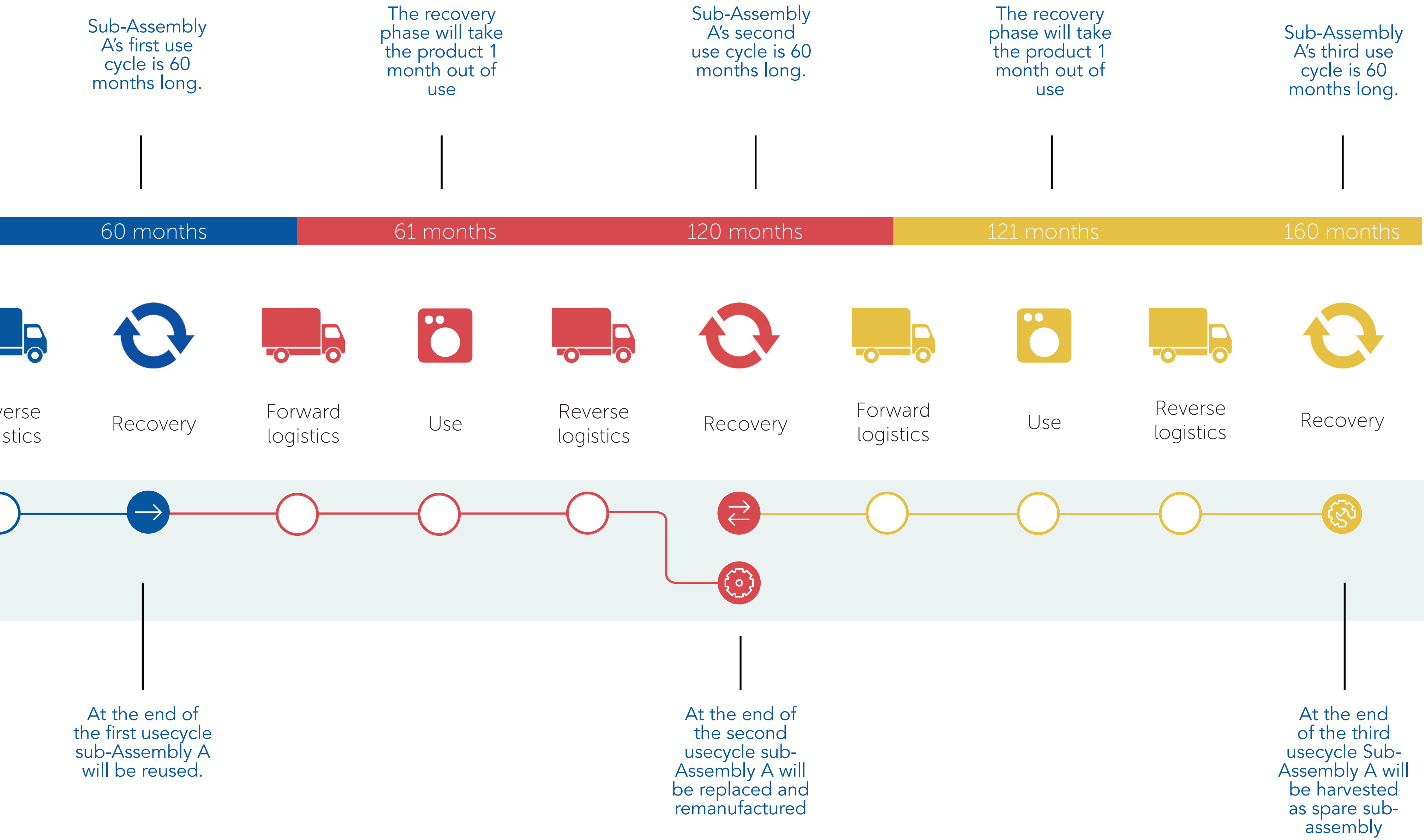


Figure 8: Deep analy



ysis of PJM swimlane

Interpretating

The visualization should be read as a timeline, as this is the best way to convey the story of the product journey. By reading each swimlane as a timeline, users can identify what happens to the sub-assembly. The required stakeholder actions are paired vertically to each step. By actively changing the sub-assembly journey section of the PJM, users can see how this will impact the stakeholder's side of the PJM.

Every swimlane reads from left to right, providing the user with the following information: to which categories does the sub-assembly belong, what happens to the sub-assembly over time and what will be the end of life scenario or the form of obsolescence. With this information in mind, designers can decide which part of the journey they would like to change using the active approach. Furthermore, designers can directly project the changes to the sub-assembly on the organization structure that facilitates the product journey and vice versa.

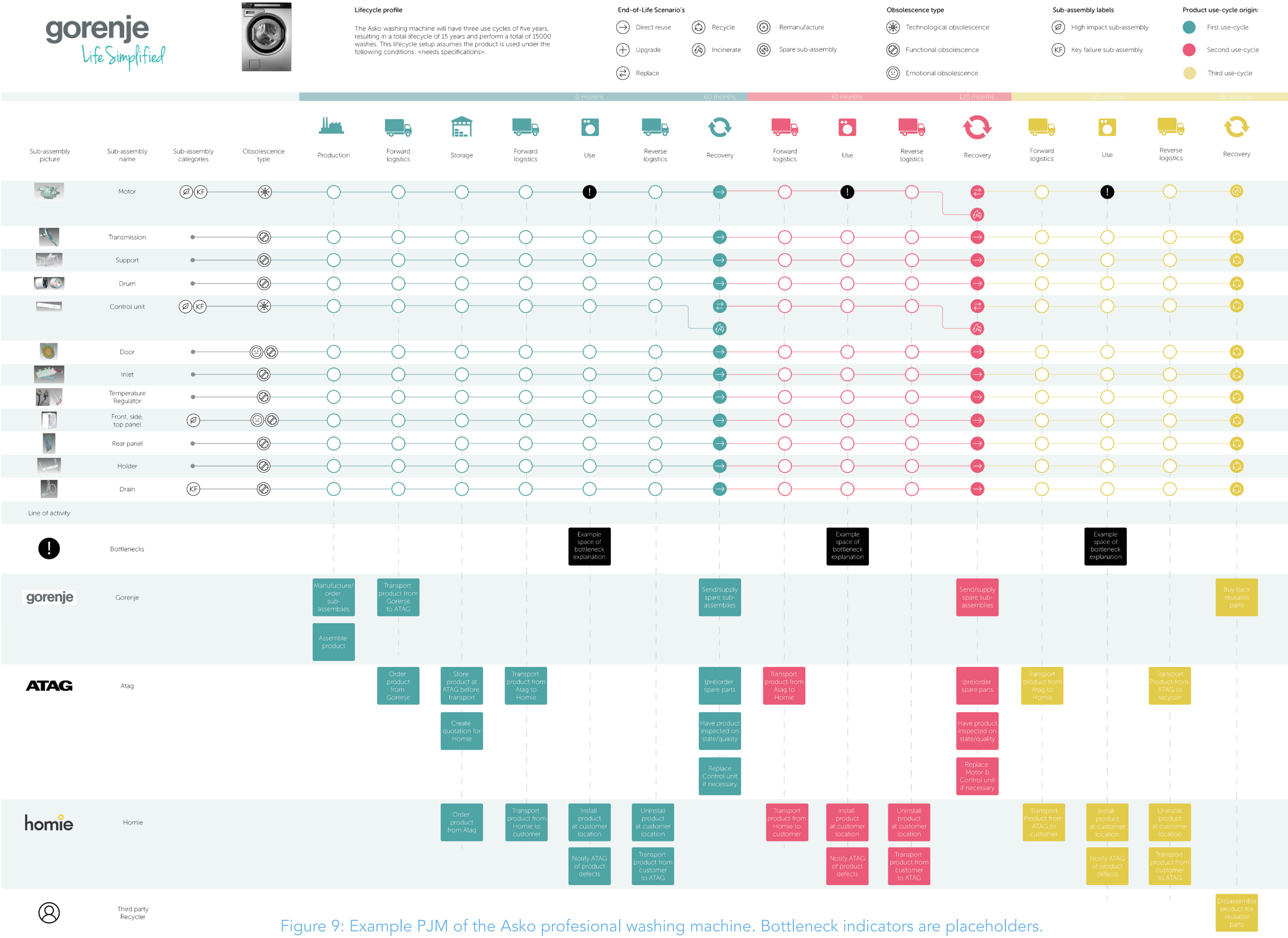


Figure 9: Example PJM of the Asko profesional washing machine. Bottleneck indicators are placeholders.

Mindset

Creating the PJM requires the users to take a long-term view, focusing on what happens over several use cycles. To utilize the PJM to its full potential, designers must have prerequisite knowledge of the following topics and concepts:

- ☐ The product to be mapped.
- ☐ The strategic disciplines.
- ☐ The product obsolescence types.
- ☐ Optional EoL scenarios.
- ☐ Information databases (Granta Edupack).
- ☐ Circular economy concepts like use cycles and life cycles.

During the prototyping sessions, the parties involved concluded that the following departments would most likely use the PJM: R&D department, program management department, repair department, and, if the company has one, the sustainability department.

Photo: Akil Mazumder

Conclusion

The earlier a company sets goals for circular design, the more influence it can have in planning ideal scenarios for its products and sub-assemblies. Current journey mapping methods are aimed at mapping material flows, customer experiences, or value streams. They do not (1) put a product center stage, (2) link required actions of stakeholders to the product and its design, and/ or (3) show opportunities to attune a product's behavior to be more circular, based on real data. The Product Journey Map allows companies to create an overview of the lifecycle flow of a product and its sub-assemblies. It specifies the actions sub-assemblies require throughout different use cycles stages and which stakeholders are required to optimally make the circular system work. The Product Journey Map is a novel design method with the potential of being valuable to design teams at companies, as identified by Gorenje and Castor Ventures. Additional testing will allow for the optimization of the procedure, data requirement, and method visual. Further testing of different products will also help adapt the method to the needs of a wide range of products.

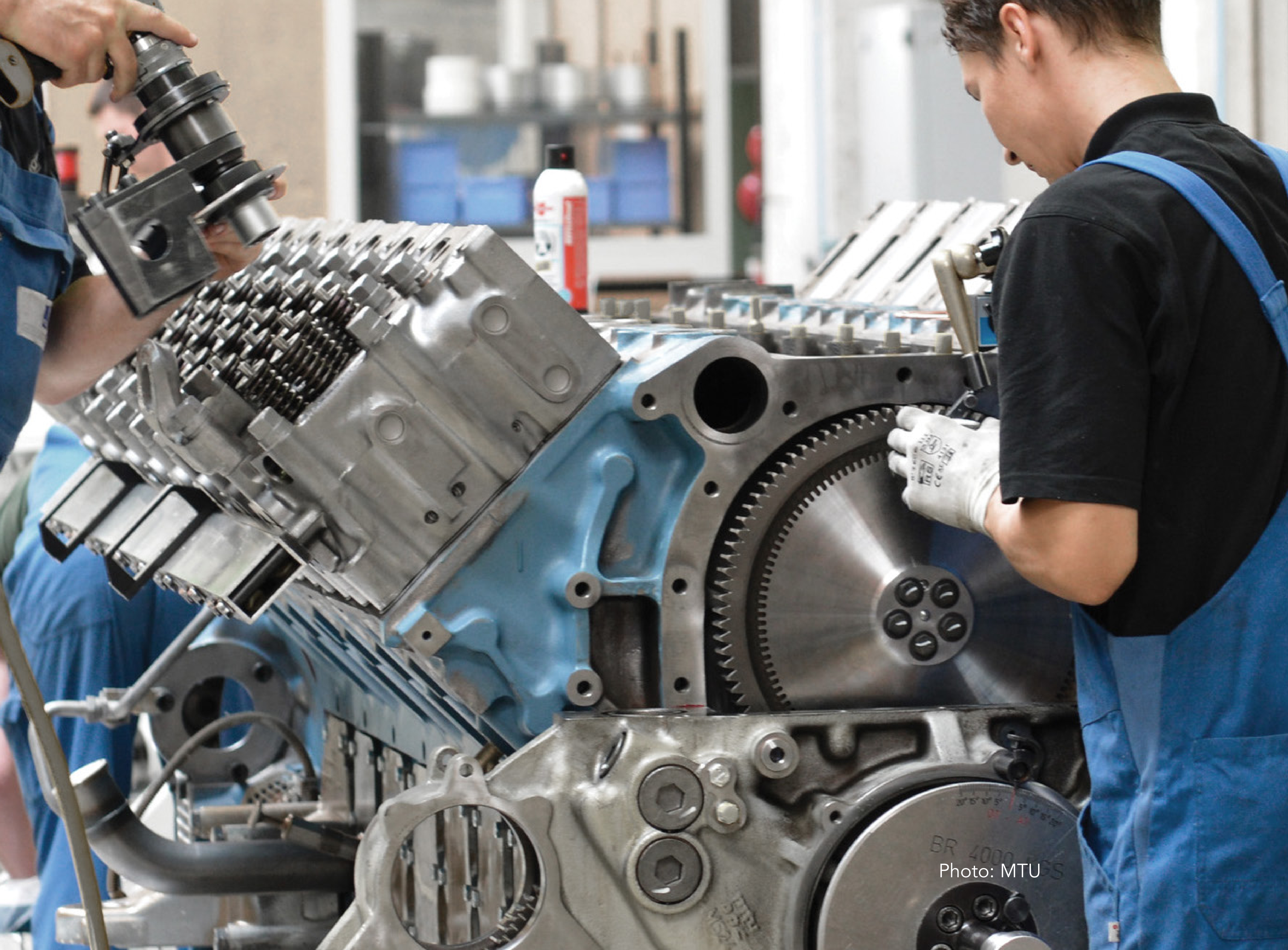


Photo: MTU

Project Journey Mapping: Towards a circular economy — project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 16 - 09 - 2021   - -   end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

To restrain the global environmental footprint of the products we use, the linear economy needs to transform towards a circular, less wasteful system. Direct reuse, repair, refurbishment and remanufacturing offer approaches towards this circular economy by extending the product lifetime beyond its first use. After products are restored, they are reintroduced to the market.

Nevertheless, products have to be made appropriately in order to make them suited for this extended lifetime. Currently, programs of requirements (in the developmental phase of a product) often don't take circular (pathways) strategies into account. Despite the growing importance of these circular (pathways) strategies, also from the European Commission, companies do not plan their products over consecutive life cycles. Questions like: what will the product have to deal with? Which stakeholders will it meet? And, what will its value proposition be? Are all important questions to consider when strategically planning out the various life-cycles of a product. Hence to aid companies in this transition, design tools and methodologies need to be researched and developed.

ReCiPSS, cofounded by the European Commission's Horizon 2020 research and innovation program, is a research program composed of two large-scale demonstrators out of the automotive industry (Bosch) and white goods industry (Gorenje group). Both demonstrators hope to contribute towards a circular economy and make a case for other companies to learn from. As stated by the Recipss project Coordinator Amir Rashid: "The main goal of the project is to demonstrate the implementation of circular manufacturing systems addressing different aspects of industrial and business environment." The program is further composed out of 13 partners, including the TU Delft, and will be coordinated by KTH.

The TU Delft ReCiPPS team is developing the Product journey map (PJM), a decision support based mapping tool for internal communication, further development and optimisation of product services. Its current goal is to map consecutive product use cycles, defining the 'pains and gains' of a product and its stakeholders over time, allowing companies to take appropriate action to develop a successful circular business model. The product journey map puts the product centre-stage and helps enhance the value capture. Currently, the PJM has gone through multiple iterations and can be found in the latest edition of the Delft Design Guide. However, according to its creators, the tool lacks a clear goal and formal structure. Therefore, this graduation project will focus on making the PJM more concrete and complete.

Lastly, being able to prototype the PJM with the ReCiPSS program demonstrators is a real opportunity for me to gain better insights into the needs of companies with circular ambitions. Nevertheless, the Corona pandemic might prove to be a limiting factor. Increases in the activity of the virus might limit interactions with demonstrators of the Recipss program and other third parties. Hence I will need to be prepared to conduct any activities online using communication platforms such as Zoom and whiteboard application such as Miro. This is something I have gained experienced in through my internship at Noorderwind.

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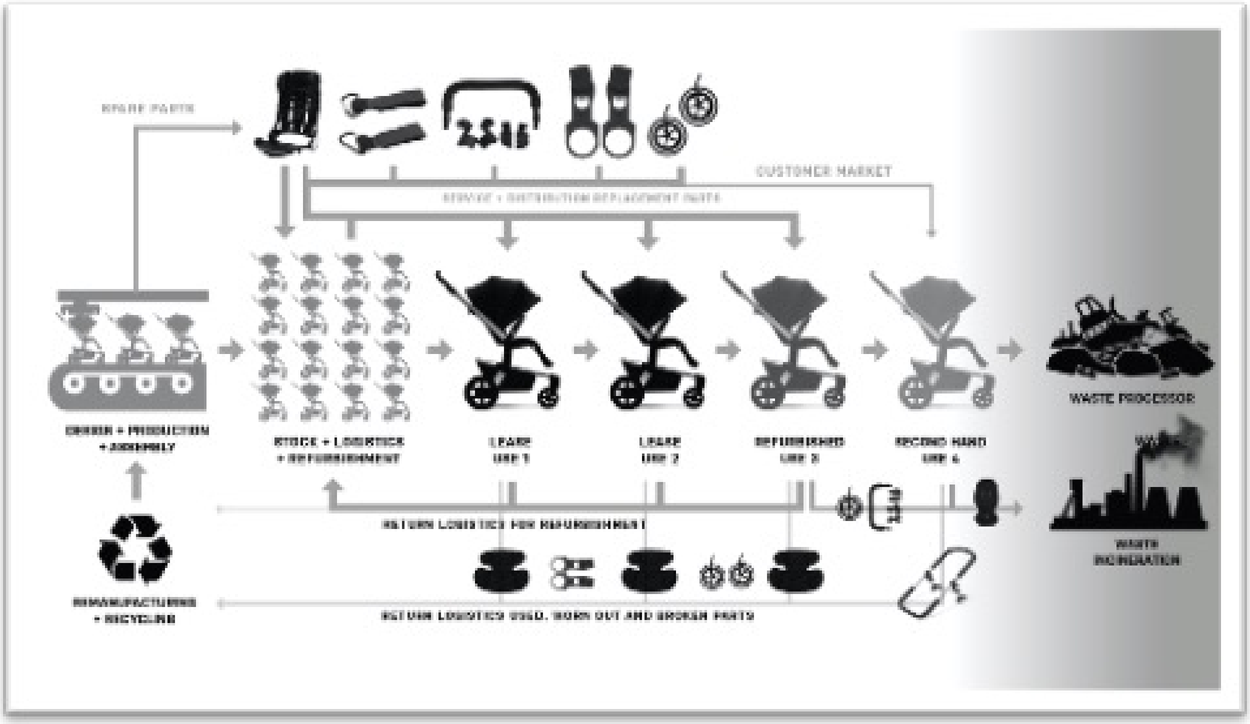


image / figure 1: Current visualisation of the Product Journey Map in the Delft Design Guide.

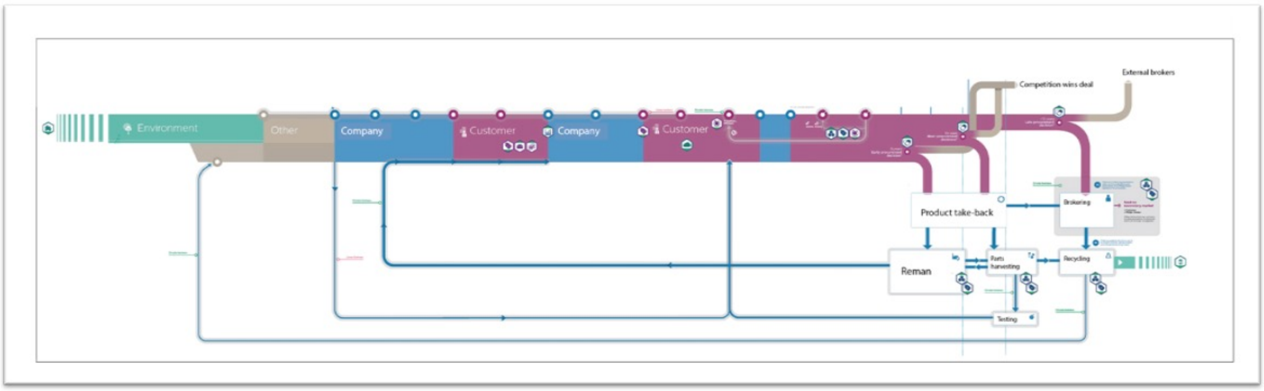


image / figure 2: Alternate Product Journey Map visualisation based on a Sankey Diagram.

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Problem definition

The current version of the PJM lacks a clear objective, formal structure, an informative and an actionable visualisation. These are necessary if companies, such as Gorenje and Bosch, want to plan their products' journeys over consecutive life-cycles to gain insight into the benefits and consequences on their industrial and business environment to further develop and optimise their product service. The problem definition is further illustrated in figure 1 and figure 2, which shows that there currently is no consensus on how to create and visualise an useful PJM.

Scope and solution space

The scope of this graduation project will be defined by the analysis of previous PJM iterations, together with expert literature on remanufacturing, data visualisation, design tool criteria and design methodologies. Through this analysis it will become clear whether the focus needs to be on creating a clear objective, a formal structure, an informative and actionable visualisation, all of them or a combination. The final deliverable will consist of a intuitive PJM which companies can use or internal communication, further development and optimisation of their product services.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

I will create an intuitive PJM containing a clear objective, a formal structure that supports this objective, an informative and an actionable visualisation. I will analyse previous versions of the PJM to gain a better understanding of their goals, analyse expert literature on remanufacturing, data visualisation, design tool criteria, design methodologies, prepare and conduct prototype sessions with the TU ReCiPSS team, ReCiPSS demonstrator parties and other companies.

This graduation project will follow an iterative double diamond approach. Based on the analysis of previous iterations of the Product Journey Map, graduation projects (e.g. Martin Steffner & Francesco de Fazio) and expert literature (e.g. remanufacturing, data visualisation, design tool criteria and design methodologies) I will determine which aspects to focus on during this graduation project (clear objective, formal structure, informative and actionable visualisation). Based on the insights gathered I will create a (design) goal for the PJM.

Accordingly, I will create a first set of iterations of the Product Journey Map. These iterations will then be discussed with the TU Delft ReCiPPS team, tested using the old cases of Bugaboo/Philips and finalised for prototype sessions with ReCiPPS demonstrator partner Gorenje and and potentially other companies.

Based on the findings of the prototype sessions and additional research, further iterations will be made in between prototyping sessions. Through this iterative cycle of creating and testing, my final deliverable will include a final iteration of the PJM with a clear objective, a formal structure that supports this objective and contains existing methodologies if necessary, an informative and actionable visualisation.

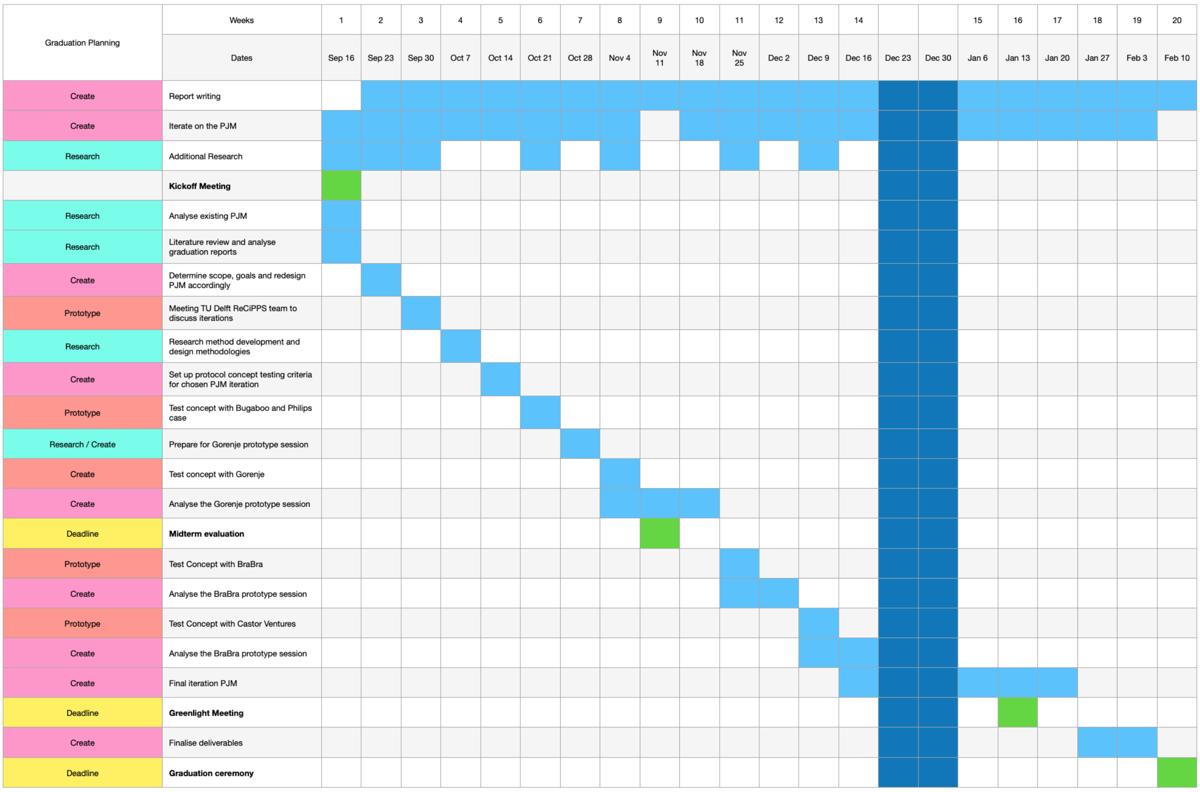
Initials & Name FSC Kooijman Student number [redacted]

Title of Project Project Journey Mapping: Towards a circular economy

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 16 - 9 - 2021   - -   end date



The above Gantt chart shows the planning for this graduation project. It follows an iterative double diamond approach (discover(research), define(create), develop(create), deliver(prototype)). The kickoff meeting will take place on 16 September 2021. During the midterm I will present the insights gained from the prototype session with the ReCiPPS demonstrator Gorenje group, together with the key learnings from my research period prior to the prototype session. Before the greenlight meeting I will have conducted and analysed 2 more prototype sessions with Feelou and Castor Ventures, allowing me to synthesis all the insights gathered throughout my graduation project and write my final draft report. All materials will then be finalised and in the last week the materials for the graduation ceremony will be prepared. In total this graduation project will take 22 weeks due to 10 holiday days.

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

Having gone through the IDE bachelor, SPD master and the TiSD annotation program, I hope to learn how to generate a strategic mapping tool, in the form of the product journey map, that companies can use to work towards new circular business models and circular (re)manufacturing of their products. The IDE bachelor and SPD master have equipped me with a deep understanding of the fundamentals of product design and the tools to exploit business resources and market opportunities. The TiSD program and master electives have allowed me to further deepen my knowledge on sustainable design, allowing me to maximise the impact design can have on markets and businesses. Hence I believe that this graduation project will provide me with the opportunity to use all skills and tools I have acquired over my academic career.

Ambitions:

To create and test clear and intuitive design mapping tool that companies can use for internal communication, further development and optimisation of their product service.

Gain more experience in preparing and giving prototyping sessions with companies. This is something I have gained experience with during my internship, however is still an underdeveloped skill for me.

Clearly communicating with and manage all stakeholders involved in my graduation project.

Improve my academic skills such as writing reports and providing concrete and useful advice.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.