Uncertainty Thinking

Embracing uncertainty in product development

Master's thesis
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nedap

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"It is the uncertainty of new product development that makes it worthwhile, because it is this uncertainty which is the source of large potential rewards for those that succeed"
(Derbyshire & Giovannetti, 2017, p. 343)

Preface

The master's thesis concludes the final part of the study Industrial Design Engineering at the University of Twente and therefore marks a milestone in my personal study career. A journey that can be characterised by a passion for product design but also a great dedication to many different extra curricular activities throughout the university and abroad. Each of these helped me to expand my knowledge and experience, meet numerous inspiring people, and most importantly grow as a person. Through these activities, my studies here and at the Kungliga Tekniska högskolan in Stockholm, I developed a great interest in the environmental and systemic context of design and product development. Design is not an isolated process, it is connected to many other processes in organisations and developments in society. This also explains why designing is a complex task. This inspired me to pursue a master's assignment that embraces this interconnected characteristic of product design and resulted in the thesis before you, namely 'Uncertainty Thinking – Embracing uncertainty in product development'.

I would like to thank the people who have helped me throughout the process of creating this master's thesis. First of all, Bjorn de Koeijer, my university supervisor, for his guidance and critical reflection during this thesis project, and his mentoring during my university studies. Our many conversations have helped and inspired me to pursue my interest in systemic design, which made it possible to work on this thesis. I also want to thank my colleagues at Nedap for our interesting discussions, including me in their projects, and their participation in my research. This provided valuable feedback on the design of the method – the Body Check Analysis. In specific, I would like to thank Roxie Muller, my company mentor. Your enthusiasm for the subject, critical attitude and guidance helped me to keep focus on this research and created an environment where I was free to explore and learn. Moreover, I want to thank the industry experts in the fields of scenario planning, transition design, innovation, and future design for our interesting and inspirational conversations.

Additionally, I want to thank the people who brought me support during this thesis project: my family, friends, and housemates who provided a listening ear to my experiences, shared my enthusiasm for my thesis and helped me through the tough times. You are amazing!

I hope that you enjoy reading this thesis!

Thomas Goudsblom
2nd of October 2023

Abstract

A high degree of uncertainty is distinctive for new product development (NPD) and causes a negative impact on the overall NPD performance. Furthermore, societal challenges (e.g., material scarcity, social conflicts, climate change) add to this uncertainty by disrupting our existing markets and way of living. Reducing uncertainty at the front end of the development process can help in creating a higher product success. Therefore, this thesis proposes a method – the Body Check Analysis (BCA) – to help in the decision-making process in product development to cope with uncertainty. A structured literature review and expert interviews that investigate the field of uncertainty and product development formed the basis for the design of the method. The method was then applied in a case study and user test for an innovation project at Nedap N.V. for evaluation. The BCA helps designers and decision-makers gain more control over uncertainty in product development by aiding the decision-making process to cope with uncertainty. It provides a structured method to identify uncertainties in the product development process, explore their potential impact, and define ways to deal with them.

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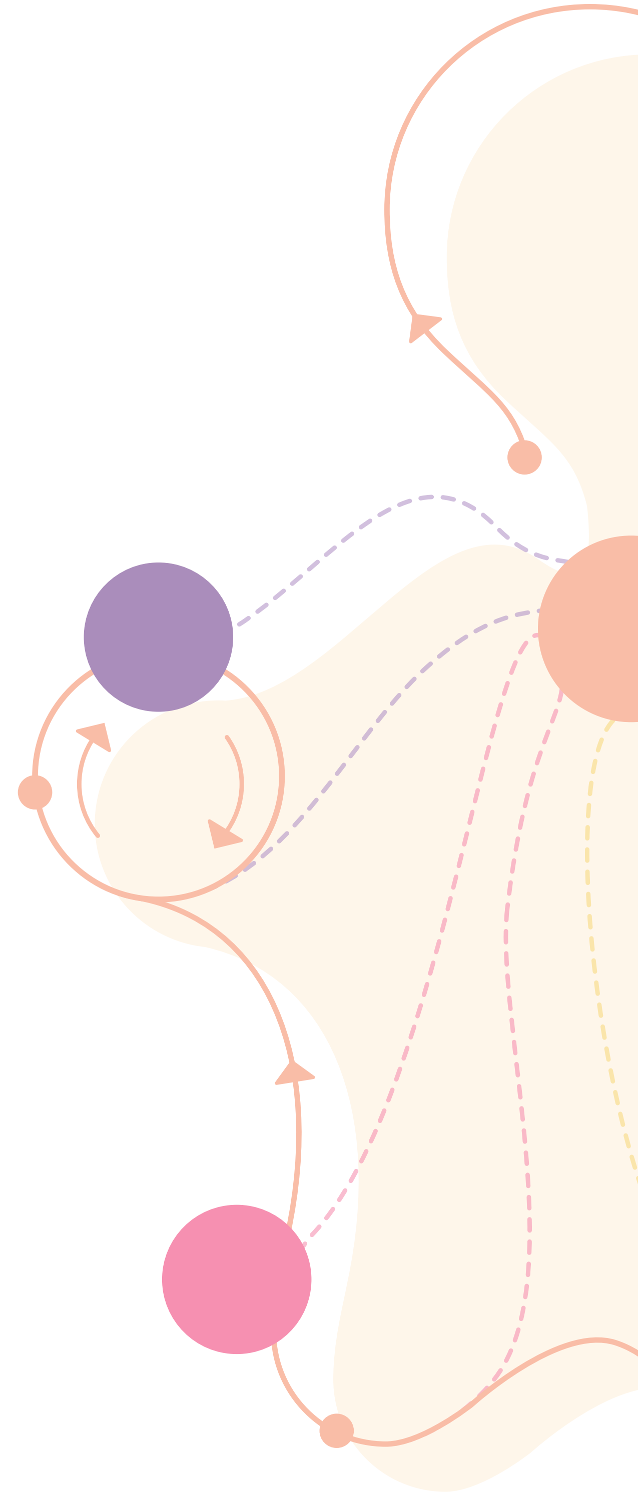

chapter 1
Introduction

New product development (NPD) is a multidisciplinary and complex process (Daalhuizen et al., 2009). Successful product innovation does not only require sound hardware or software engineering, it also needs to be successfully embedded into the market and society (Smits, 2002; Van der Duin, 2006). However, our society is constantly changing and the grand challenges humanity faces are becoming more intangible and unpredictable (e.g. food security, material scarcity, social conflicts, climate change, etc.). Our society is becoming more connected due to amongst others globalization, which helps in the rapid development and distribution of technology, beliefs and solutions. However, these rapid developments and changes also disrupt our existing markets and way of living, and increase the uncertainty we have of what our world of tomorrow will look like, and the roles we play in our future society (Kaivo-oja & Lauraeus, 2018). Not only as individuals or designers but also as communities, organisations or companies. When moving from the global to the local level, we recognise that these societal transformations ask for an approach that helps us to work with a high degree of uncertainty on a practical level. How can we embed a practice into our professional lives that actively allows us to embrace the uncertainty the world brings us to create better and more successful product-solutions?

Due to these developments and the character of new product development, a high degree of uncertainty is very distinctive for NPD (Derbyshire & Giovannetti, 2017), and causes a negative impact on the overall NPD performance (Lasso et al., 2020). Reducing uncertainty at the front end of the development process can help in creating a higher product success (Herstatt et al., 2004). Therefore, on an organisational level, this asks for an embedded systematic practice that helps in the decision-making process in product development to cope with uncertainty.

This research aims to develop such a systematic practice for Nedap to help them gain more control over uncertainty in product development. Nedap is a technology-driven product development company that creates high-impact, hard and software solutions that help people to work more efficiently. Their headquarters are located in Groenlo the Netherlands, from which their seven business units operate in different markets worldwide. These markets range from retail to security, to healthcare, and livestock management (Nedap N.V., 2023b).

This thesis concludes the final part of the Master’s programme in Industrial Design Engineering at the University of Twente. In the course of this chapter the research questions, the design research approach and the structure of the thesis are discussed.

1.1 Design research approach

The main goal of the thesis is to develop an approach that aids the decision-making process for product development at Nedap to cope with uncertainty. This is done by providing a practical and a knowledge contribution to Nedap. The knowledge contribution aims to deepen the understanding of uncertainty in product development and forms the foundation for the practical contribution that focuses on the design of an approach to cope with uncertainty in the decision-making process of product development. For each of these goals, research questions have been formulated that provided focus and direction in attaining these goals. Together, these research questions should help answer the main question of this thesis:

'How can an approach be developed to aid the decision-making process for product development at Nedap to cope with uncertainty?'

Sub-research questions:

RQ1: How to cope with uncertainty in the decision-making process of product development?

a) What existing approaches can be used in the decision-making process to cope with uncertainty?

b) What are the important elements from these approaches that should be implemented in the product development process at Nedap?

RQ2: What value could an approach offer for product development at Nedap?

a) How should the approach be implemented in the product development process at Nedap ?

RQ3: How can an approach convey or address the actions and information required to aid the decision-making process in product development?

Knowledge contribution of this research

Creating an understanding of uncertainty itself and the role of uncertainty in product development is essential for the design of an approach. To answer the first and second research questions, uncertainty itself and its role in product development are investigated through semi-structured interviews with industry experts outside of Nedap[1], a structured literature review, and semi-structured interviews with industry experts within Nedap. The interviews with experts from outside of Nedap helped to create an understanding of the breadth of the research domain and develop a foundation for the structured literature review (e.g. selecting topics or keywords relevant to the goal of the research). Through the structured literature review, discussed in chapter 2.1, the existing knowledge and research available on topics relevant to the goal of this research were studied. This formed a basis to investigate the product development process at Nedap and the role uncertainty plays here through conducting semi-structured interviews with industry experts within Nedap, which is discussed in chapter 2.2.

The design research approach and the structure of the thesis are represented in Figure 1.1.A.

[1] The industry experts from outside of Nedap provided the research with expertise and knowledge to shape the basis of the structured literature review. The background of these experts can be found in Scenario planning at Shell, Strategy development at Jester Strategy, Foresight & Innovation management at EDHEC Business School and 'Stichting Toekomstbeeld der Techniek', Design Thinking & Responsible Futuring at the University of Twente.

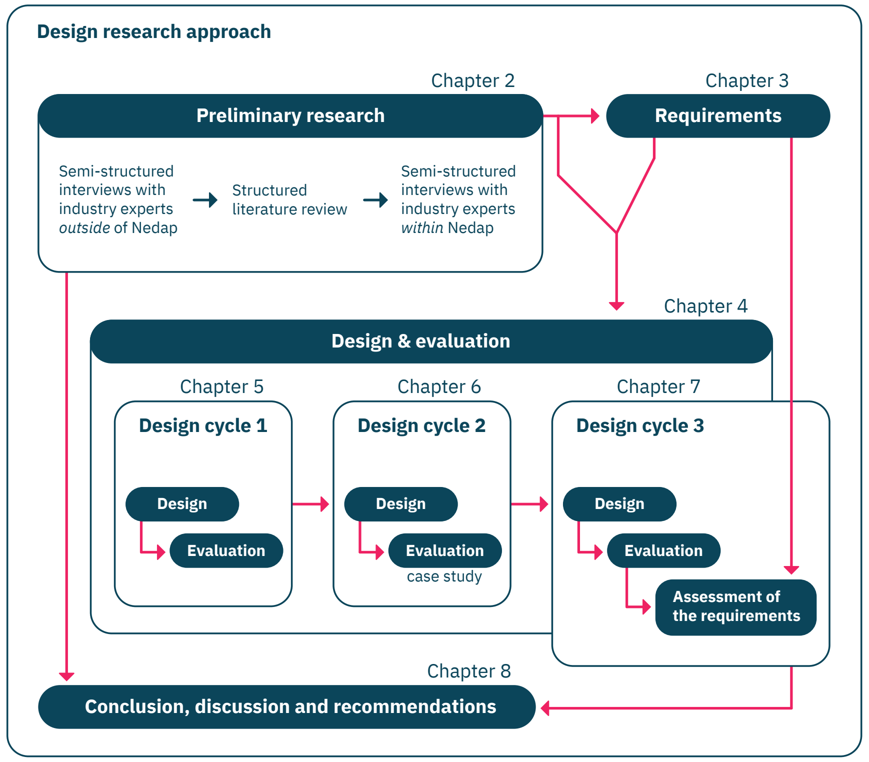

Figure 1.1.A – Design research approach. This figure shows the structure of this thesis and how the different elements are connected.

Practical contribution of this research

Designing an approach that Nedap can apply to cope with uncertainty in the decision-making process of product development transforms the created understanding of the knowledge goal into a practical application. To answer the third research question, and to add to the answer of the second research question, a method was designed and tested in various evaluation settings. Among which a case study where the designed method was applied to an 'Innovation project at Nedap'. The design and evaluation process consisted of three design cycles, where in each design cycle a design was created and evaluated, and used as input for the succeeding design cycle. The design and evaluation process is introduced in chapter 4, where also the design rationale is discussed. The foundation of the design is presented in chapter 5, followed by chapter 6 where a more detailed design is discussed in combination with the case study. In chapter 7, and the attached guidebook of the Body Check Analysis, the final design is presented.

chapter 2

Preliminary research

This chapter is used to formulate a set of requirements based on preliminary research into the field of uncertainty and product development. The research was done through a combination of a structured literature review and expert interviews.

The literature review examines the main principles and theories of uncertainty in product development. These theories will address the following main topics:

- Why should uncertainty be considered?
- What is uncertainty?
- How to cope with uncertainty?

The expert interviews examine the product development process and the relationship between uncertainty and product development activities. This is done by conducting semi-structured interviews with industry experts from within Nedap.

These sections will mainly address research questions 1 and 2, as presented in chapter 1.1. At the end of this chapter, the preliminary research is concluded.

2.1 Literature review

A structured literature review was applied to study the existing knowledge and research available on topics relevant to the goal of this research. Explorative online research, in combination with conversations with industry experts, shaped the selection of keywords for the structured literature search. This resulted in the following search matrix, see Table 2.1.A. The keywords in this search matrix have been constructed into four topics, following columns A to D: A) topics relevant and adjacent to 'designing for uncertainty', B) the core focus of this research, C) the application domain of this research, and D) the format of the searched research.

Table 2.1.A – Search matrix for the structured literature review.

	A	B	C	D
1	Future* (Future / Futures / Future studies)	Uncertainty	Design	Method* (Method / methodology)
2	Foresight	Innovation	Product Development	Framework
3	Forecast* (Forecasting)		Implementation	Approach
4	Change		Management	
5	Anticipation		Decision-making	

The structured literature review was executed in the following way:

1. First, the keywords were entered in Google Scholar in the following combinations: Column A+C, B+C, A+C+D, and B+C+D, where all unique combinations of keywords have passed. The combination A+B+C+D was not entered, as a test search with this combination with keywords from the first row did not yield new results that had not yet been uncovered with the previous combinations. For each of the combinations, the first 20 results had been saved. In total, this yielded 2800 papers.
2. Applying the first filter: selecting papers based on the language and title of the paper. To pass this filter, the paper should be written in English and the title should be relevant to the focus of the research. This brought the total of 2800 down to 925 papers.
3. Applying the second filter: for this selection, the abstract and keywords were read, and the overall layout of the document and the conclusion were scanned for their relevance to the focus of the research. This brought the total of 925 down to 184 that were suitable for reading. In this filter, also papers that were not available, have been taken out of the collection.
4. Reading the papers. The papers within the selection of 184 papers were ranked on the priority of their topics and relevance to the focus of the research. Out of these papers, 64 papers have been completely read, and the most relevant ones are discussed in this thesis.

2.1.1 Why should uncertainty be considered?

New product development (NPD) is an important process for companies, as it helps to, if successful, ensure future revenue and keep the product portfolio up-to-date. However, a high degree of uncertainty is also very distinctive for NPD (Derbyshire & Giovannetti, 2017). This does not only impact the behaviour of people in engineering design work itself (Cash & Kreye, 2018) but also has a negative overall impact on the NPD performance by "making activities and decisions more challenging" (Lasso et al., 2020, p. 3.). Consequently, it negatively impacts the quality of design decisions made. Therefore, for designers, it is important they are able to deal with uncertainty or seek to control uncertainty to a certain extent (Beheshti, 1993). By reducing uncertainty in the front end of the development process and ensuring less variation from front-end specifications during the entire project execution, a higher product development success can be created (Herstatt et al., 2004).

From the past decades, numerous examples can be recognised of how uncertainty in product development activities impacts the overall performance of an organisation, and how different approaches in coping with uncertainty can change this impact. Polasky et al. (2011) show examples of two major corporations and how their different approaches to dealing with uncertainty changed the impact on their organisation:

> "During the 1980s, IBM did not use scenario planning and, as a result, greatly underestimated the market for personal computers. The company retreated from a market that became more than 100 times larger than its forecasts [32]. By contrast, Shell used scenarios to evaluate long-term decisions. Even though oil prices were low in 1970 and predicted to remain so, scenario planners from Shell considered alternate states, including some in which a consortium of oil-producing countries limited production and drove oil prices upward. Shell hedged against this case by changing its strategy for refining and shipping oil. This exercise in scenario planning allowed Shell to adapt more rapidly than its competitors to price increases during the mid-1970s and it rose to become the second largest oil company in the world [33]." (Polasky et al., 2011, p. 401)

As the example above already shows, within the decision-making process some decisions have a higher significance and are more impactful than others. Derbyshire & Giovannetti (2017), describe these types of decisions as crucial decisions, as they tend to "change the very circumstances in which the decision is taken in the first place, such that no future decision can ever be made in the same circumstances again" (p.335). Moreover, they are also likely to invoke highly unpredictable responses from competitors, that can lead to numerous changes over a long time, and are indeterministic of character. Below is an example of a few crucial decisions and the extreme impact they can cause can be seen:

> "Apple successfully innovated touchscreen and internet-enabled mobile technology, introducing their highly-innovative iPhone product in the mid-2000s (Mazzucato, 2015). As a result, the previously-dominant market-leader, Nokia, never fully recovered its market position, resulting in its decline and eventual sale to Microsoft. The correct decisions leading to the creation of a product with strong capabilities in relation to touchscreen and internet-enabled technology, made by Apple, and the incorrect decisions, or failure to make similar decisions in time, by Nokia, forever changed the strategic landscape of the mobile-phone market, such that no future decision could be made under similar circumstances again." (Derbyshire & Giovannetti, 2017, p. 336)

Although a logical response to the consequences of a high degree of uncertainty in NPD would be to aim to fully eliminate uncertainty in the design process, in reality, this is either not possible or doing so would completely constrain the effectiveness of decision-making. Instead, using approaches that help to cope with or reduce the uncertainty, or minimize the impact of uncertainty on design-decisions would work much better (Beheshti, 1993; Sniazhko, 2019). Hence, the approach to be designed must increase the ability of designers to control uncertainty. To investigate when and how to apply such an approach, first, a better understanding needs to be created about uncertainty and the new product development process.

Uncertainty and the new product development process

New product development (NPD) is a multidisciplinary and complex process and is crucial to a company's survival (Daalhuizen et al., 2009). Uncertainty is not only very distinctive for NPD, as discussed earlier, but it is also experienced in a multiplicity of ways, meaning a variety of different forms of uncertainties are perceived in NPD (Lasso et al., 2020). In ideal NPD, the level of uncertainty is gradually reduced throughout the development process (through decision-making) to a minimum when the product is launched. However, in reality, environmental developments and changes constantly create new uncertainties throughout not only the entire development process but also the entire life cycle of the product, see Figure 2.1.B (Jetter, 2003).

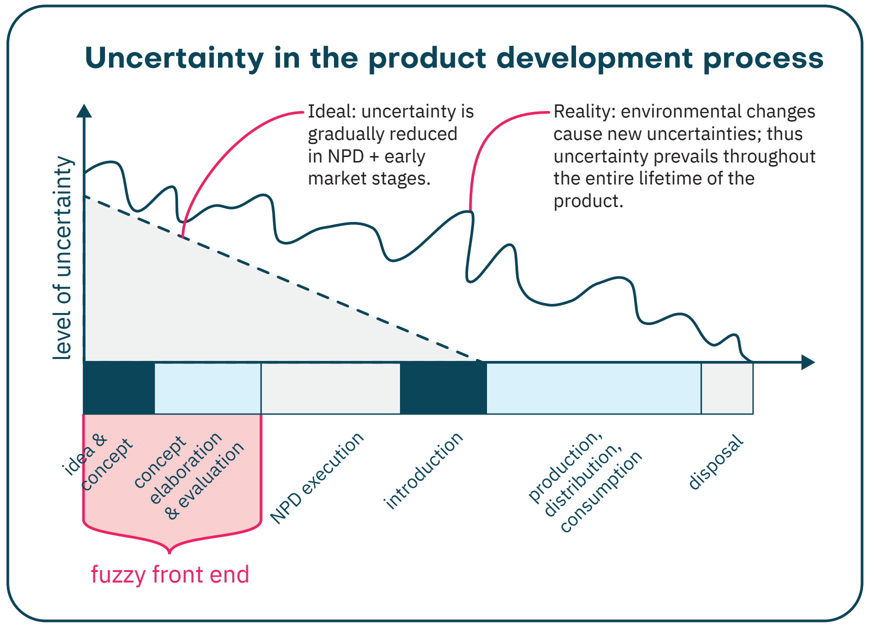

Figure 2.1.B – Uncertainty in the product development process. Adapted from Jetter (2003) and Herstatt et al. (2004).

Within the product development process, the fuzzy front end of product development tends to hold the highest degree of uncertainty, see Figure 2.1.B (du Preez & Louw, 2008; Herstatt et al., 2004; Jetter, 2003; Lindemann & Lorenz, 2008; Sperry & Jetter, 2009). During this part of the development process not only is largely determined which development projects will be executed, but also the costs, quality and time frame are defined to a great extent. As such, the fuzzy front end bridges the gap between strategic activities (i.e. product portfolio planning and generating product ideas based on environmental scanning) and specifying product development tasks (Jetter, 2003). The research by Herstatt et al. (2004), also identified the fuzzy front end as the greatest weakness in product development. Therefore, the fuzzy front end seems to be the most logical phase in the product development process to apply an approach to cope with uncertainty.

Apart from investigating the product development process itself, knowing the type of innovation project can provide substantial insight into the degree of uncertainty. Radical innovation is known to be more uncertain than incremental innovation, because radical innovation concerns more dimensions, such as new market, new product and new technology (de Oliveira et al., 2015; Van der Duin, 2006). Innovation projects for new product development can generally be classified into four categories: market penetration, market development, product development and diversification, see Figure 2.1.C (Lynn & Akgün, 1998; Meldrum & McDonald, 1995; Nelson et al., 2013). Projects that hold a higher degree of uncertainty, such as evolutionary innovation (i.e. market development and product development) and radical innovation (i.e. diversification) could benefit more from applying an approach to cope with uncertainty than incremental innovation (i.e. market penetration) (see Figure 2.1.C).

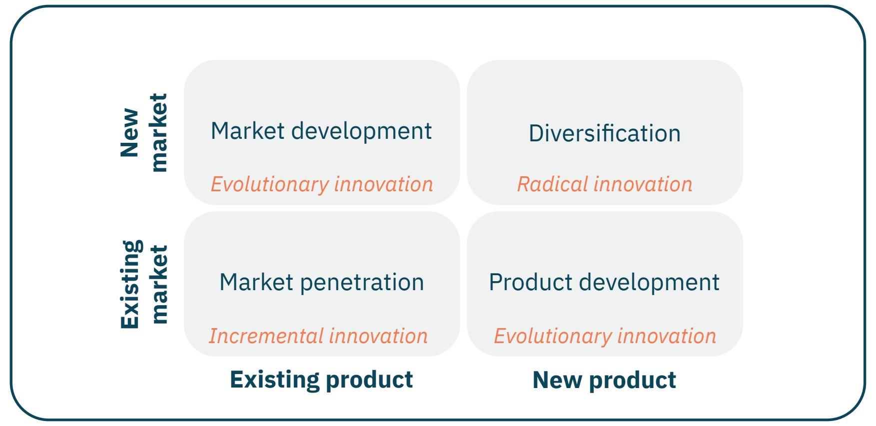

Figure 2.1.C – Classification of the type of innovation project. Adapted from Lynn & Akgün (1998), Meldrum & McDonald (1995) and Nelson et al. (2013).

2.1.2 What is uncertainty?

Before discussing how to cope with uncertainty, first, it should be discussed more in-depth what uncertainty is. Discussing the perspectives of different authors will help to get a better understanding of uncertainty and the complexity of the concept. In literature, 'uncertainty' is described as an amorphous concept expressing the probability certain assumptions made in the decision-making process are incorrect, or the presence of unknown facts that could have a strong impact on the future state of a product, system or strategy and its success (De Weck et al., 2007). This characterizes the term 'uncertainty' to demonstrate a certain degree of 'vagueness' (Thunnissen, 2003), or 'indefiniteness' and 'unreliability' (Lasso et al., 2020). Which expresses itself in the lack of knowledge (De Weck et al., 2007; Sniazhko, 2019; Wynn et al., 2011), lack of trust in knowledge or lack of definition (Wynn et al., 2011) about the future state of events (Sniazhko, 2019). Herstatt et al. (2004), apud Galbraith (1973), defines 'uncertainty' in a very practical way, as "the difference between the amount of information required to perform a particular task, and the amount of information already possessed by the organisation (p. 4)".

It can be recognised uncertainty has a strong connection to a different concept, namely 'risk'. This causes the terms in some situations to be used interchangeably. However, there are certain differences. Risk describes "an uncertain event or condition that, if it occurs, has a positive or negative effect on a project objective. A risk has a cause and, if it occurs, a consequence." (Project Management Institute, 2000, p. 127). For example, the cause may be labour shortage, the risk event is that there is no adequate labour for the task, and the consequence may be delayed project planning. The origin of risk can be found in the uncertainty that is present in all projects (Project Management Institute, 2000; Ward & Chapman, 2003). Whereas risk describes the situation or condition under which all potential outcomes and their probabilities of occurrence are known to the decision-maker, uncertainty describes the situation where such information is (partly) unknown to the decision-maker. This includes not only the outcome and probability of occurrence of a situation or condition but also how a situation or condition will develop (Park & Shapira, 2017; Vries, de & Toet, 2022). As uncertainty is the origin of risk, applying an approach to cope with uncertainty allows to examine the root-cause of both concepts and define ways to deal with them.

For this research, the following definition will be used when discussing 'uncertainty', inspired by the definitions discussed above:

> *Uncertainty describes a deficiency between the amount and quality of information in possession, and the amount and quality of information required to make a decision or to perform a specific task. Moreover, it describes the presence of unknown information that could have a strong impact on the future state of a product, system or strategy and its success.*

Open this fold-out page on the right-bottom to view **Table 2.1.D**.

A clear definition of uncertainty is important for this research to create a common understanding of the concept when applying the approach in the product development process at Nedap. As can be seen in the section above, in literature alone there is already much variety in the definition of uncertainty. Among the different stakeholders involved in the product development process, this will most likely not be any different.

Having a definition will help to create an understanding of what uncertainty is, however, it does not provide a structure that allows one to work with the concept of uncertainty and ultimately cope with it. The next two sections, 'Sources of uncertainty' and 'Shapes of uncertainty', aim to provide this structure. This is done by diving deeper into the origin of uncertainty in product development and the different shapes and forms it can be experienced.

Sources of uncertainty

Investigating the source of uncertainty provides a first step in coping with uncertainty (Rowe, 1994). In line with the definition of uncertainty, also among the sources of uncertainty, no shared framework can be found in the literature. Hence, the work of different authors is reviewed to identify the most important sources where uncertainty comes from. These are used to describe the broad ecosystem of sources of uncertainty that should be taken into account when designing the approach. The outcome of this review is presented in Table 2.1.D.

When reviewing Table 2.1.D, a few observations can be made. Several distinct sources of uncertainty are reoccurring throughout the different literature. These are technology, market, resource allocation, and organisational. Hence, it is important to consider these when designing an approach to cope with uncertainty. Specifically, the categorization by the research of De Weck et al. (2007) stands out as it describes more sources compared to the other research. Also, the environmental uncertainty as described by Jetter (2003) stands out. It leans towards describing the broader ecosystem in which product development takes place, as also is done in the research by De Weck et al. (2007).

Based on the research discussed, the following sources of uncertainty are used to describe the broad ecosystem of sources of uncertainty that should be taken into account when designing the approach:

> *technology, organisational, resource allocation, use context, partners, suppliers, competitors, market, politics & regulations, culture & society, natural environment.*

This is done by comparing the interpretation of the different sources presented in each of the studies and extracting the reoccurring elements. In this process, it was important to present a broad, yet distinctive, set of sources that can describe the ecosystem. Such a diverse set of sources will help in identifying the uncertainty experienced in product development. In Appendix A.1, each of these sources is explained.

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Author and publication title			
Educating the Guess: Strategies, Concepts and Tools for the Fuzzy Front End of Product Development. By **(Jetter, 2003)**	Implementing a Learning Plan to Counter Project Uncertainty. By **(Rice et al., 2008)**	Exploring the link between uncertainty and project activities in New Product Development. By **(Lasso et al., 2020)**	A classification of uncertainty for early product and system design. By **(De Weck et al., 2007)**
Technological uncertainty Technological performance; availability of technology	**Technical** Completeness and correctness of underlying scientific knowledge; how well technical specifications of the product can be implemented; reliability of manufacturing processes; maintainability	**Technology** The degree to which the underlying scientific (technical) knowledge of the new product is understood and can be transformed into a physical product (Hooge et al. 2016)	**Product context** o Understanding of technology o Reliability of a component o The durability of a component o Unmodelled interactions between parts of the system
Market uncertainty Customer requirements; (future) competition; market requirements	**Market** Understanding customer needs and wants; how well conventional forms of interaction between customer and product can be used; how well conventional sales and distribution methods can be used; understanding the relationship between product innovation and competitors' products	**Market** The degree to which markets are defined, including the customer needs and wants being understood (Song, Jinhong, and Di Benedetto 2001)	**Market context** o Suppliers o Competitors o The role of competitors and suppliers o Understanding the demand profile for a product o Economics How well the general economy is understood
Uncertainty about resource allocation When to allocate resources to a project; how much resources to allocate to a project	**Resource allocation** Financial resources; competencies	**Resource allocation** Lack of understanding regarding the continuity of resources, being financial or competence-based that can be critical to the success of the project (O'Connor and Rice 2013)	
	Organisational Strategic commitment; organisational resistance; lack of continuity; changes in internal and external partners; inconsistency in expectations	**Organisational** The gap between the capabilities an organisation possesses and it's needs (Galbraith 1974)	**Corporate context** o Company strategy o Maintenance contracts o Contractual agreements
Environmental uncertainty Economic; ecological; social; political;			**Political & cultural context** o Natural environment or climate (e.g. disasters) o Regulations; changing regulations that impact the design of products o Political decisions that affect the behaviour of markets (e.g. warfare) o Cultural forces (e.g. fashions, trends)
			Use context o Skills of operators and potential users o The operational environment of the product (i.e. climate, terrain, weather conditions) o How the product will be used

Table 2.1.D – Overview of the sources of uncertainty, discussed from the perspective of four different authors. In the first row, the authors are shown and the focus of their research is presented. In the columns, the categorization of the different sources of uncertainty by the different authors is viewed.

Shapes of uncertainty

Uncertainty comes in many different shapes and forms. To help understand how to identify and cope with uncertainty, an uncertainty taxonomy can be applied to map the broad spectrum of uncertainties, see Figure 2.1.E. De Weck et al. (2007), makes an important distinction between known and unknown uncertainty.

> For known uncertainty, one (i.e. the organisation) is capable of recognising and identifying the presence of the uncertainty. This uncertainty can both be reducible and irreducible. Reducible uncertainty often relates to a lack of definition or lack of knowledge, and with additional effort, this ambiguity or lack of knowledge can be reduced, as the issues are relatively well understood. Examples are the reliability of technical components, or corporate strategy and commitment. Irreducible uncertainty can only be 'explained' by the occurrence of future events. Examples are the results of a sports match, election, or the value of a portfolio on the stock market in a year. Often, it can be possible to approach the possible outcome(s) of such uncertainties. However, completely reducing the uncertainty will not be possible.
>
> For unknown uncertainty, one (i.e. the organisation) is not capable of recognising and identifying the presence of the uncertainty. Hence, it is also not possible to reduce the uncertainty. Although, these unknown facts might still have a strong impact on the future state of a product, system or strategy and its success. Here, the goal lies in first 'revealing' the uncertainties before any other actions can be taken. However, even after the best possible uncertainty analysis, some uncertainty may remain, called residual uncertainty (Courtney et al., 1997).

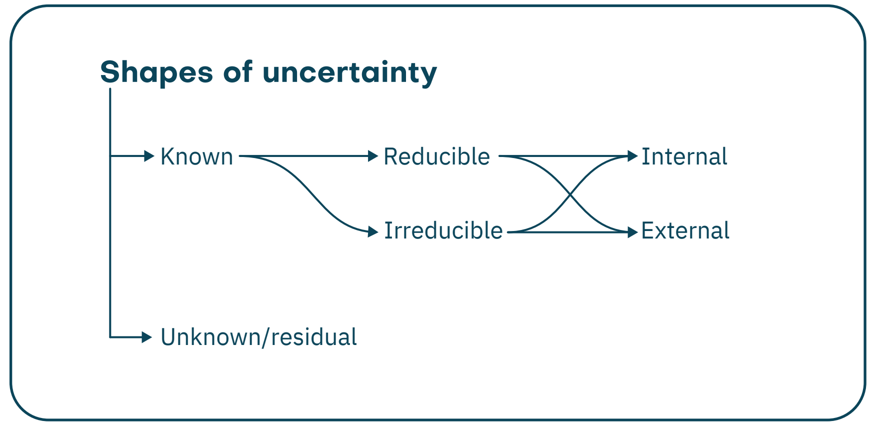

Figure 2.1.E – Taxonomy of the different shapes of uncertainty (De Weck et al., 2007; Courtney et al., 1997).

Next to the known and unknown uncertainty, De Weck et al. (2007), also describes the 'sphere of influence' or 'system boundary' to distinguish between internal and external sources of uncertainty, see Figure 2.1.E & Figure 2.1.G. Internal uncertainty arises from within the system (i.e. organisation), and can often be influenced by the designer of the organisation to a greater extent (e.g. the product or corporate context). External uncertainty arises from outside the system (i.e. organisation) and is often beyond the direct control of the designer and the organisation (e.g. the market, or environmental and political context).

This sphere of influence can also be found in the work by Stephen Covey: Seven Habits of Highly Effective People. Haimes & Schneiter (1996), compared the work by Covey to systems engineering and concluded how the elements of the different approaches not only correspond to each other but also complement one another. The Circle of Influence/Circle of Concern can be used to describe the system domain from a holistic perspective, see Figure 2.1.F. Successful problem-solving or decision-making requires an understanding of the different elements within the system. As such, the circles can help shape the problem-definition and decide on which elements of the problem to focus on. The two frameworks (Figure 2.1.E and 2.1.F) in combination with the 11 identified sources of uncertainty have been synergized to create the adapted framework presented in Figure 2.1.G.

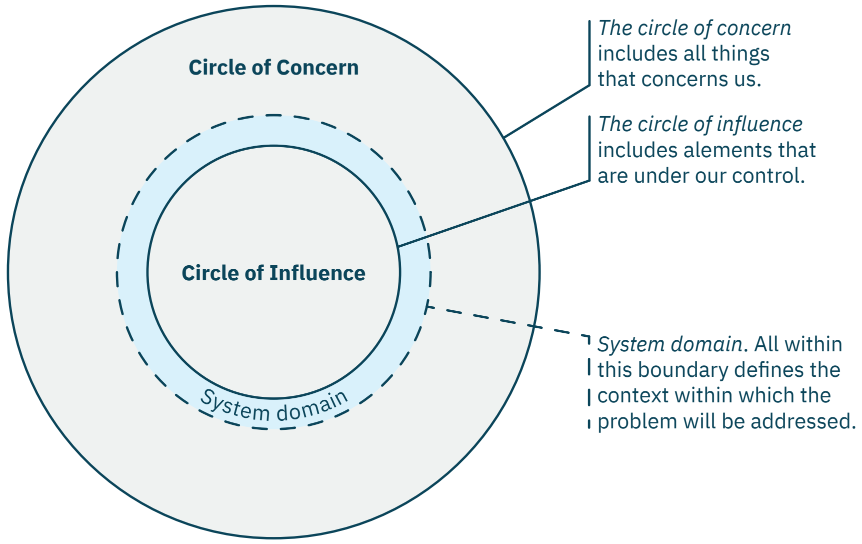

Figure 2.1.F – Covey's Circle of Influence/Circle of Concern (Haimes & Schneitner, 1996). Elements of the system domain outside of the circle of influence are of primary concern as they are beyond our control but are relevant to the problem context.

Not only does this help to build a basis for an uncertainty taxonomy, but it also helps to gain more insight into the level of influence an organisation can have over certain uncertainties, find appropriate approaches to deal with these uncertainties and decide which uncertainties to focus on first.

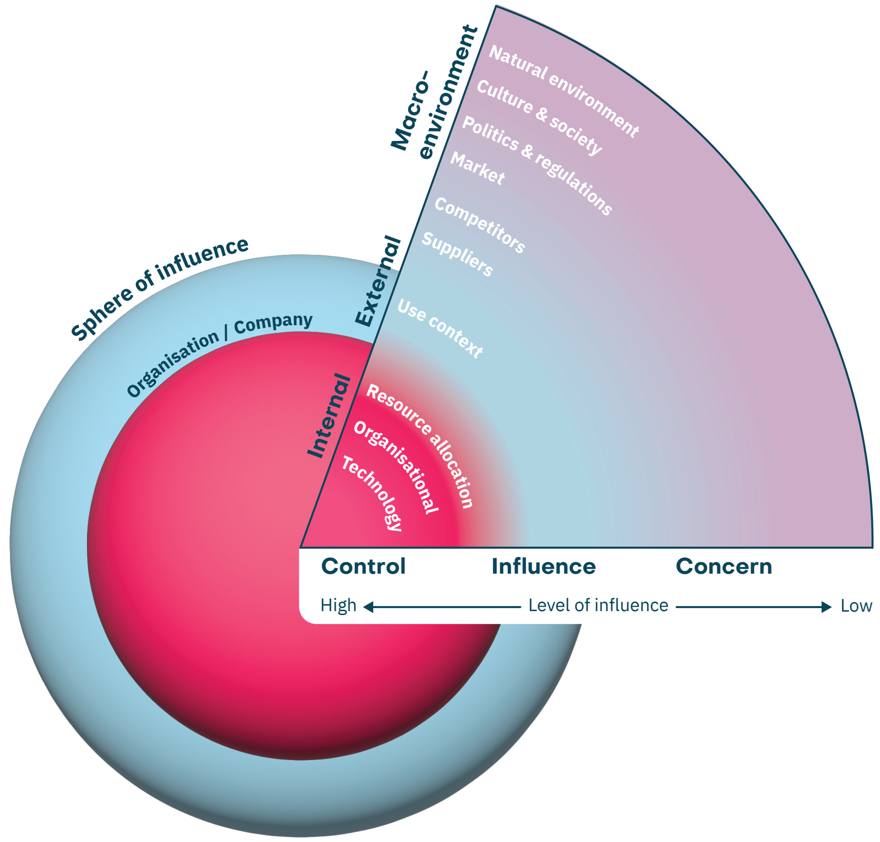

Figure 2.1.G – Sphere of influence. The sphere of influence showcases the level of influence an organisation can have over different sources of uncertainty (adapted from De Weck et al., 2007 and Haimes & Schneiter, 1996). Along the y-axis, the 11 different sources of uncertainty are shown. In the inner circle, the domain of the organisation (i.e. Nedap) is represented. Which corresponds to the circle of control as presented on the x-axis. The second circle showcases the sphere of influence and captures those uncertainties the organisation can influence to a certain degree. The remaining uncertainties lie on the spectrum between the sphere of influence and the circle of concern. Also, the nature of the sources of uncertainty are shown and categorize the sources in 'internal', 'external' and 'macro-environment'. The system domain describes the context within which the problem will be addressed and can be mapped as a circle anywhere on the y-axis. The magnitude of the different circles (i.e. organisation, sphere of influence, system domain) can be dependant on the project and/or organisation.

2.1.3 How to cope with uncertainty?

The literature discussed helps to create an understanding of what uncertainty is and its relationship with product development. To design an approach to aid the decision-making process for product development at Nedap to cope with uncertainty, different existing approaches to deal with uncertainty are investigated. Through this investigation, important elements that can be applied in the design of the approach are selected. In this section, this investigation will be discussed. First, the different postures that can be taken towards uncertainty in product development are described. Secondly, the existing approaches are discussed.

Postures towards uncertainty

Essential to the process of product development are designers, or more specifically, the decision-makers. They shape the problem-definition and guide the proposition (i.e. product solution) through the innovation or product development process. Different postures can be taken towards uncertainty, and these highly influence how uncertainty can be coped with. Lipshitz & Strauss (1997), identified three basic postures towards uncertainty among people in decision-making; reducing, acknowledging and suppressing uncertainty. The applied posture can be dependent on both the working culture and the cultural background within an organisation. The working culture functions as an enabler to efficiently cope with uncertainty (Terje Karlsen, 2011), whereas the cultural background can influence the degree of uncertainty avoidance. This describes the extend to which people are able to tolerate uncertainty and ambiguity (Herstatt et al., 2004).

> The most obvious posture is reducing uncertainty, where additional information is collected before a decision is made, or a decision is postponed until the additional information can be collected. Often, this additional information is simply not available and the uncertainty can only be reduced by extrapolating available information from the past and present. Also, assumption-based reasoning can be applied where gaps in the information required for decision-making are filled by making assumptions. However, experience is required to do this efficiently. A combination of the approaches can be found in mental simulation or scenario building, where possible future developments are imagined in a structured way (Herstatt et al., 2004; Lipshitz & Strauss, 1997; Sniazhko, 2019).
>
> In many situations, uncertainty reduction is not feasible or too costly. The posture of acknowledging uncertainty provides an alternative, where decisions are made while taking into account potential uncertainties (or risks) and how these can be confronted or avoided. For example, organisations can build in buffers to protect themselves from temporary component shortages or can adopt a more flexible product development strategy that allows them to easily change the course of action when required. Also, a combination of assumption-based reasoning and preparing for uncertainties is possible (Jetter, 2003; Lipshitz & Strauss, 1997; Sniazhko, 2019).
>
> Finally, the posture of suppressing uncertainty can be recognised, where uncertainty is ignored or only symbolically addressed. For example, through denial or ignoring undesirable information. Often, a false sense of security is created through the believe that [a described outcome] will not happen (Lipshitz & Strauss, 1997).

While deciding how to respond to uncertainty, it is essential to consider what posture fits the situation best. Moreover, avoiding the posture of suppressing uncertainty is critical at all times.

When implementing a formal approach to cope with uncertainty, Terje Karlsen (2011) apud Hillson (1997) argue that organisations need a framework against which they can compare their current practice. Hillson (1997) introduces the uncertainty management maturity model that structures this framework into four levels;

1. *Naïve*: The organisation is unaware of the need to manage uncertainty.
2. *Novice*: A few people within the organisation have started applying practices to manage uncertainty but no generic, structured approach is employed.
3. *Normalized*: Managing uncertainties is part of normal business processes and is implemented consistently for most projects. Generic processes are formally applied and an integrated set of tools and techniques is used by the organisation.
4. *Natural*: An uncertainty-aware culture is characteristic of the organisation that results in a proactive approach to managing uncertainty in all elements of the business and focusses on opportunity management.

To assess the maturity level of an organisation four attributes are suggested; process, application, experience, and culture. These are explained in Table 2.1.H. Each of these attributes is required to build towards a higher maturity. However, it can be recognised that without the attribute 'process', it is difficult to establish the other attributes.

Table 2.1.H – Attributes to assess the maturity level of an organisation in effective management of uncertainty (Hillson, 1997; Terje Karlsen, 2011).

Attribute	Description
Process	The availability and quality of the applied processes within the organisation structure the process of management of uncertainty.
Application	Consistent application of the processes to all the projects is needed. The required resources need to be committed to these processes and well-developed supportive tools and approaches should be available within the organisation.
Experience	In-house knowledge, skills and experience about the specific processes and tools are required. Moreover, supportive systems within the organisation should be in place for managing uncertainties, such as employee development programmes, procedures, knowledge management systems, manuals for managing uncertainty, etc.
Culture	A supportive organisational culture towards managing uncertainties is needed. This is characterised by among others a positive attitude towards uncertainties, commitment of time and resources, high understanding and integration of uncertainty management and a focus on opportunities. The main factors that contribute to this culture are knowledge, communication, commitment, openness, and trust.

Approaches to cope with uncertainty
When choosing approaches to cope with uncertainty in product development, it is important to evaluate the suitability of the approach for the intended use situation or project. In this section, five relevant approaches from the literature review to cope with uncertainty will be introduced and their possible added value and drawbacks will be discussed. At the end of this section, an overview of the main findings can be found. Here, the most important elements of these existing approaches are stated that should be considered in the design of an approach to cope with uncertainty in the decision-making process of product development.

The levels of uncertainty
The level of uncertainty that surrounds a project can help in selecting the most suitable approach. In other words, Courtney et al. (1997) argue, that not all approaches to cope with uncertainty are appropriate to apply in all situations, or will even be deemed ineffective in some cases. No approach can make uncertainty go away, but some will lead to more confident and informed decisions. To determine what approaches to use, the level of uncertainty is defined in four distinct levels, each presenting its own set of suitable approaches (Courtney et al., 1997; Helmrich & Chester, 2022; Vries, de & Toet, 2022):

Level 1: A Clear-Enough Future
Level 2: Alternate Future
Level 3: A Range of Futures
Level 4: True Ambiguity

For a description of each of these levels, examples and their matching approaches, see Appendix A.2.

The approach by Courtney et al. (1997) breaks the assumption that by simply applying a set of strong analytic tools clear decisions can be made. However, when the environment becomes more uncertain, no amount of analysis through applying these analytic tools will help to predict the future. The levels of uncertainty confront decision-makers to systematically think about uncertainty. On one side, it acts as a guide to select the approaches and tools that can help in decision-making at the different levels of uncertainty for various projects. On the other side, it is a framework that helps tackle the most challenging decisions in projects that need to be made. When designing an approach to cope with uncertainty, the 'levels of uncertainty' by Courtney et al. (1997) can help in selecting approaches that match the level of uncertainty in a product development project.

Uncertainty management
In uncertainty management, sometimes referred to as risk management, a set of tools, processes, techniques and methodologies are applied within organisations to manage uncertainty, or more specifically to reduce negative outcomes. Uncertainty management is seen as an essential practice to deal with the inevitable uncertainty that is experienced within projects and businesses throughout all levels of organisations. The general uncertainty management process can be described in four stages and is represented in Table 2.1.I (Kutsch & Hall, 2009; Terje Karlsen, 2011).

Table 2.1.I – General stages of the uncertainty management process (Kutsch & Hall, 2009; Terje Karlsen, 2011).

Stage	Description
1 – Uncertainty management planning	Define the activities that should be done to approach project uncertainties.
2 – Uncertainty identification	Identify uncertainties that could affect the project goals.
3 – Uncertainty analysis	Evaluate the consequences and the likelihood of the uncertainties.
4 – Uncertainty response	Develop techniques and procedures to mitigate the uncertainties, keep track of the uncertainties, identify new uncertainties, and implement an uncertainty-response plan.

The general stages of the uncertainty management process as presented by Kutsch & Hall (2009) and Terje Karlsen (2011), provide a structured approach to coping with uncertainty on a general level. This could be used as a foundation for designing an approach to cope with uncertainty in the decision-making process of product development at Nedap. However, the uncertainty management approach does not provide guidance to select specific tools and techniques that are suitable for the specific project or the execution of the approach.

Coping with uncertainty by applying NPD project activities
Investigating the NPD process shows there are three distinct project activities that are executed throughout the product development process; information project activity, knowledge sharing project activity, and representation project activity, see Figure 2.1.J (Cash & Kreye, 2018; Lasso et al., 2020). These project activities represent the actions performed by individual members of a project team. In their research, Lasso et al. (2020), examined the link between uncertainty and project activities and identified a connection between specific sources of uncertainty and the project activities executed to cope with this uncertainty, see Figure 2.1.J.

The approach proposed by Lasso et al. (2020), provides guidance in the decision-making process by highlighting the importance of responding to the nature of uncertainty in NPD projects. Moreover, it helps to select what project activities are most appropriate for what situations, and which are not. However, before the approach can be applied, first, the nature and source of the uncertainty in the NPD project need to be identified. Hence, the approach to be designed should aid in identification of uncertainty and the source(s) from which uncertainty is emerging.

Project activities in new product development

Project activity	Definition	Examples
Information project activity	Exploitation of objective data to improve processes or outcomes (Hult, Ketchen, and Slater 2004). Is related to gathering, processing, and archiving data.	Seeking data from sources such as files, books, internet, documents, journals, and other such sources (Ulrich and Eppinger 2003) Action motivated by uncertainty to acquire objective data to answer specific questions (Cash and Kreye 2018).
Knowledge sharing project activity	Actions and interactions in project teams where they exchange and integrate knowledge expressed with respect to their understanding and beliefs, linked to developing shared understanding (Hult, Ketchen, and Slater 2004).	Acquiring or exchanging knowledge with others from the same or different departments in the company or even from suppliers or customers (Wiener 2018) Can be actioned in the form of regular meetings and training events (Hult, Ketchen, and Slater 2004), telephone conversations (Davenport, De Long, and Beers 2014), and email exchanges (Wasiak et al. 2011).
Representation project activity	Practices by which team members externalize their understanding of certain elements of the product to, for example, evaluate its physical attributes in relation to the NPD goal (Ulrich and Eppinger 2003).	Prototyping, product mock-ups, and computational simulation (Fox et al. 1998) Connects physical and mental simulation, where an individual tests their understanding by creating and manipulating external representations (Christensen and Schunn 2009).

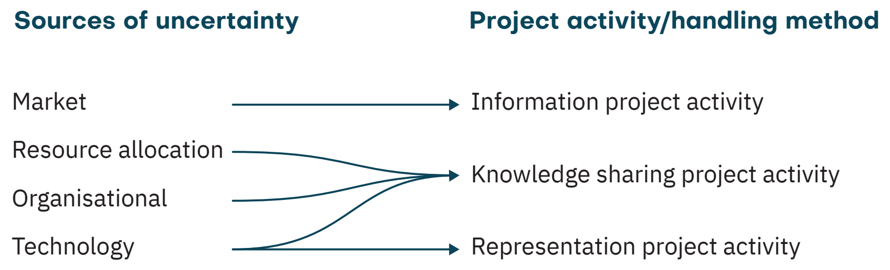

Figure 2.1.J – Project activities in NPD and their relationship to 4 sources of uncertainty (Cash & Kreye, 2018; Lasso et al., 2020).

Simulation and scenario planning

Many of the traditional approaches and tools for product development and engineering, that rely on historical data or consumer judgement, are not suitable to support the product development process of (radically) new products to cope with uncertainty. For these types of projects, the historical data is often not available and the judgement of consumers (e.g. to define product specifications or estimate sales) is not reliable as the consumers often have insufficient prior experience with similar products (Derbyshire & Giovannetti, 2017; Jetter, 2003).

The traditional approaches and tools are used to build and apply mental models that simulate real-world situations to support decision-making. However, due to the character of NPD (i.e. uncertain, complex, new), different approaches and tools are required to adequately build and apply these mental models (Jetter, 2003). Scenarios can be applied to build these mental models. They address the challenge of uncertainty about future developments holistically by considering multiple possible future situations and trends, rather than only aiming to predict a few elements based on historical data. This way, they can help assess the success of a new product in different future environments and allow to investigate various decisions and their consequences. Moreover, they employ a degree of robustness in the product development process to design products that yield desirable results regardless of what future scenario comes true. (Bradfield et al., 2005; Derbyshire & Giovannetti, 2017; Gausemeier et al., 1998; Goudsblom et al., 2022; Graessler et al., 2016; Jetter, 2003; Nelson et al., 2013).

When developing scenarios, external members can be used for two different reasons; 1) to facilitate the process of developing scenarios, an experienced scenario practitioner is used, and 2) outside experts that have knowledge of the industry and a strong understanding of their environment are used to stimulate and challenge the thinking of the team and solve specific problems. This last-named group is also referred to as ‘remarkable people’ (Bradfield et al., 2005). The approach can be used to investigate uncertainty, identify early warning signals, promote flexibility and environmental monitoring of the organisation, and test assumptions to help cope with uncertainty. However, it heavily relies on soft data[2] and can occasionally have too little focus on the decision at hand (Drew, 2006; Vries, de & Toet, 2022).

[2] Soft data describes information about things that are difficult to measure such as people’s opinions or feelings (Cambridge Dictionary, 2023).

Simulation and scenario planning provides a specific technique that can be applied to examine uncertainty. Hence, for the design process, this technique could potentially be used in combination with other approaches that provide structure to the uncertainty analysis process, however, lack specific tools or techniques.

Creating a learning organisation
Implementing a Leaning Plan can support a product development team to deal proactively with (high) uncertainty in innovation projects through the development of innovation personnel. The Learning Plan is structured through different learning loops that each consist of two stages. The first stage of this plan encourages teams to systematically investigate each of the different sources of uncertainty to identify gaps in knowledge and create an overview of the information that is known. This is done to help prioritize the most critical uncertainties, how these uncertainties can be reduced, or how assumptions made can be tested. The second stage of this plan evaluates what is being learned in the first stage. The learning loop is evaluated with the team's oversight board where the learnings, assumptions, tests and ways to reduce the uncertainty are presented, and is agreed upon the steps for the next learning loop (Rice et al., 2008).

This approach provides on the one hand a framework for dealing with high uncertainty and on the other hand a methodology for guiding and monitoring progress for the development of innovation personnel in dealing with uncertainty. Moreover, it also enhances the working culture within an organisation to support innovation. Following Hillson (1997) and Terje Karlsen (2011), this is one of the attributes required to effectively deal with uncertainty.

When designing an approach to cope with uncertainty, adopting a learning plan can help in the integration of the approach into the organisation. Moreover, it could help in training innovation personnel to cope with uncertainty through consistent application of an approach.

Main findings of the 'Approaches to cope with uncertainty' section
In the previous section, five different approaches from the literature review to cope with uncertainty have been presented. For each of these approaches, their potential value and drawbacks for the design of an approach to cope with uncertainty in the decision-making process of product development have been discussed. Below, the most important findings of this section for the design of an approach to cope with uncertainty can be found:

- Applying the levels of uncertainty by Courtney et al. (1997) can help in selecting approaches that match the level of uncertainty in an innovation project. Integrating these levels into the design can help to tailor the provided tools and techniques more specifically to the innovation project. However, to do this, the design should help in determining the level of uncertainty first.
- Uncertainty management by Hillson (1997) and Kutsch & Hall (2009) provides structure to the process of coping with uncertainty on a general level. This can be used as a foundation for the design.
- The approach by Lasso et al. (2020) highlights the importance of responding to the nature of uncertainty in NPD and helps to select what product development activities are most suitable for what situations. Therefore, it is essential the design can aid in identification of uncertainty and the source(s) from which uncertainty is emerging.
- Simulation and scenario planning can be used to assess the success of a new product in different future environments and allow the investigation of various decisions and their consequences. This technique can be used in the design to examine uncertainty more in-depth, especially when a high level of uncertainty is experienced in the innovation project.
- The learning plan by Rice et al. (2008) can be used to help integrate the design and its application into the organisation. Furthermore, it could help in educating personnel in coping with uncertainty.

2.2 Expert interviews

Within product development, decision-making is an important process that occurs on a variety of both different levels within the organisation, as well as at different moments within the product development process itself. The expert interviews have been conducted to get a better understanding of the product development process at Nedap and the role uncertainty plays here to decide how an approach to cope with uncertainty in product development should be implemented at Nedap. This is done by examining the product development process of Nedap itself, the relationship between uncertainty and the product development process, and the relationship between uncertainty and the different decision-making levels within the organisation. Seven semi-structured interviews with industry experts from within Nedap have been conducted to achieve this.

Goals and objectives of the interviews
The goal of the interviews is to collect evidence to decide how an approach to cope with uncertainty in product development should be implemented at Nedap. This evidence will be used in addition to the insights obtained through the structured literature review. To achieve this goal, the interviews intend to help understand the following:
- The different decision-making processes that are executed within product development at Nedap;
- The degree of uncertainty experienced throughout these processes;
- The degree of impact or consequences created by the outcome of the decision-making processes;
- The frequency of the decision-making processes.

These three factors – uncertainty, impact and frequency – are important to help decide how and where in the product development process an approach should be integrated. Ideally, the approach is used for decision-making processes that are characterized by:
- a high degree of uncertainty,
- the outcome of decisions made here has a high impact,
- and the decision-making processes are often executed and thus have a high frequency.

This way the approach is designed for (a) part(s) of the product development process that can gain the highest benefit from the application of an approach that aids in coping with uncertainty.

Method
The method will discuss the overall set-up and structure of the semi-structured interviews and describe how the semi-structured interviews will be evaluated. This qualitative approach has been chosen as it allows to combine a pre-determined set of open questions (that prompt discussion) with the possibility of exploring specific responses or themes further. Moreover, the approach fits well with the exploratory nature of the research of this thesis and helps to build a stronger knowledge base for the design of the approach.

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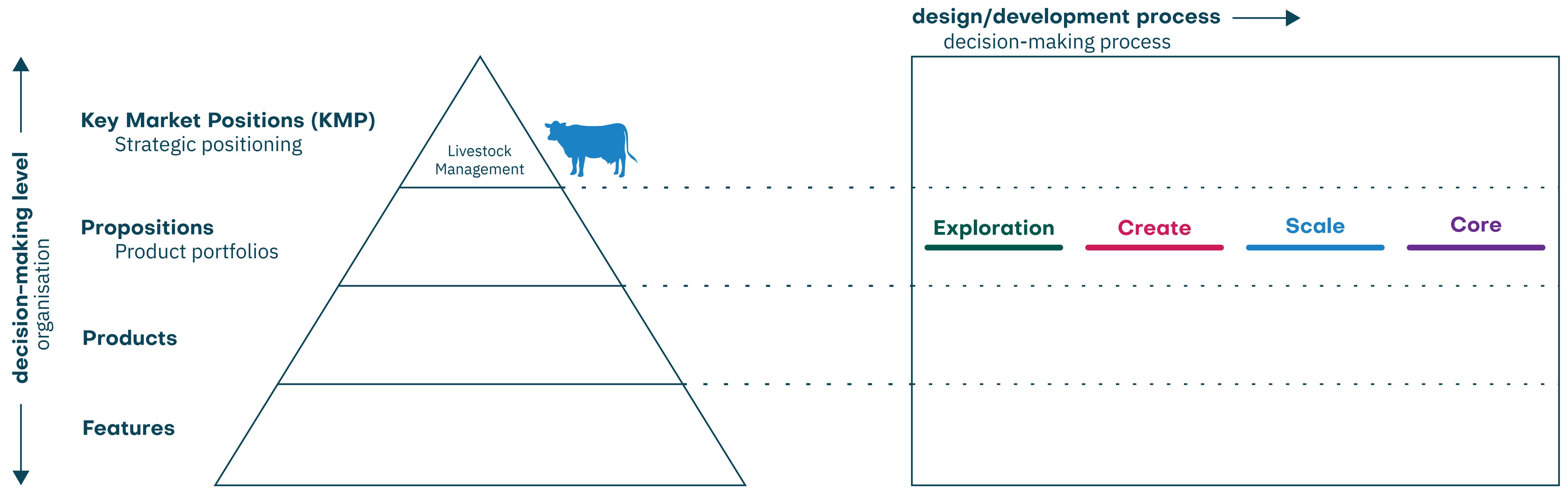
Thematic framework



Uncertainty within a decision-making process

Uncertainty describes a deficiency between the amount and quality of information in possession, and the amount and quality of information required to make a decision or to perform a specific task. Moreover it also describes the presence of unknown information that could have a strong impact on the future state of a product, system or strategy and its success.

Examples of uncertainty
There are many different types or sources of uncertainties that can be experienced within a decision-making process. Below, some examples are given:

Internal uncertainty	External uncertainty
-Technological / Reliability	-Market (i.e. demand, economic)
-Resource allocation	-Competitors
	-Suppliers / Partners
-Use context	
	-Politics / Regulations
-Company strategy	-Environmental (nature)
-Organisational	-Culture & Society

Impact of a decision

The impact describes the influence the outcome of a decision has on the current and future state of the **product** (i.e. proposition), **organisation** (i.e. Nedap) [***internal factors***], **competitors**, **market**, and **environment** [***external factors***].

The influence can be both positive (i.e. acceleration in development, or greater success in market) and negative (i.e. discontinuation of project, or failure) of nature.

Frequency of a decision-making process

The frequency describes the rate of occurrence of a decision-making process. Decision-making itself can be described as the process of choosing a course of action, based on gathering information and assessing alternatives.

What is a decision?
In the design/development process, decision-making is repeatedly used to choose a course of action to move from an identified problem towards an implemented and successful solution. The specific '*course of action*' is sometimes also referred to as '*design-decisions*'.

Crucial decisions
In the decision-making process both *small* and *big* decisions need to be made. Crucial decisions "change the very circumstances in which the decision is taken in the first place, such that no future decision can ever be made in the same circumstances again" (Derbyshire & Giovannetti, 2017, p. 335). This implies the decision made cannot be redone at a later moment, with the same circumstances.

Figure 2.2.A – Thematic framework. The framework was used as a conversation piece during the interviews to create a shared understanding of the different decision-making processes in product development and definitions such as uncertainty, impact and frequency.

Setup of the semi-structured interviews
To get a proper understanding of the product development process at Nedap and provide structure to the interviews, a thematic framework was created that explains the most important objectives of the interview (see Figure 2.2.A, open the fold-out page on the left). This thematic framework was used as a conversation piece during the interviews to create a shared understanding of the different decision-making processes in product development and definitions such as uncertainty, impact and frequency. The framework was created by making an overview that maps the different levels and processes of decision-making in product development within the Livestock Management organisation at Nedap and explains the previously mentioned definitions. This overview is based on the general stages of market adoption of propositions at Nedap (see Figure 2.2.B, representing a part of the proposition lifetime development process, and functioned as an example of a decision-making process during the interviews), and the organisational structure of the organisation (representing the different levels of decision-making). The explanation of the definitions was based on the literature review. Next, participants were invited for an interview based on their work-experience, and experience within one or more parts of the product development process or levels of decision-making within the organisation, see Table 2.2.C.

Apart from the thematic framework, a template was made that can record the qualitative input of the interviewees, see Figure A.3.A in Appendix A.3. Interviewees would write notes or make drawings on these templates during the discussion. This template provided a Likert scale for each of the three concepts – uncertainty, impact and frequency – on the y-axis, and space to either place the product development process or the different decision-making levels on the x-axis. Using the Likert scale allowed the qualitative input provided by the interviewees to be better comparable by creating a common reference point.

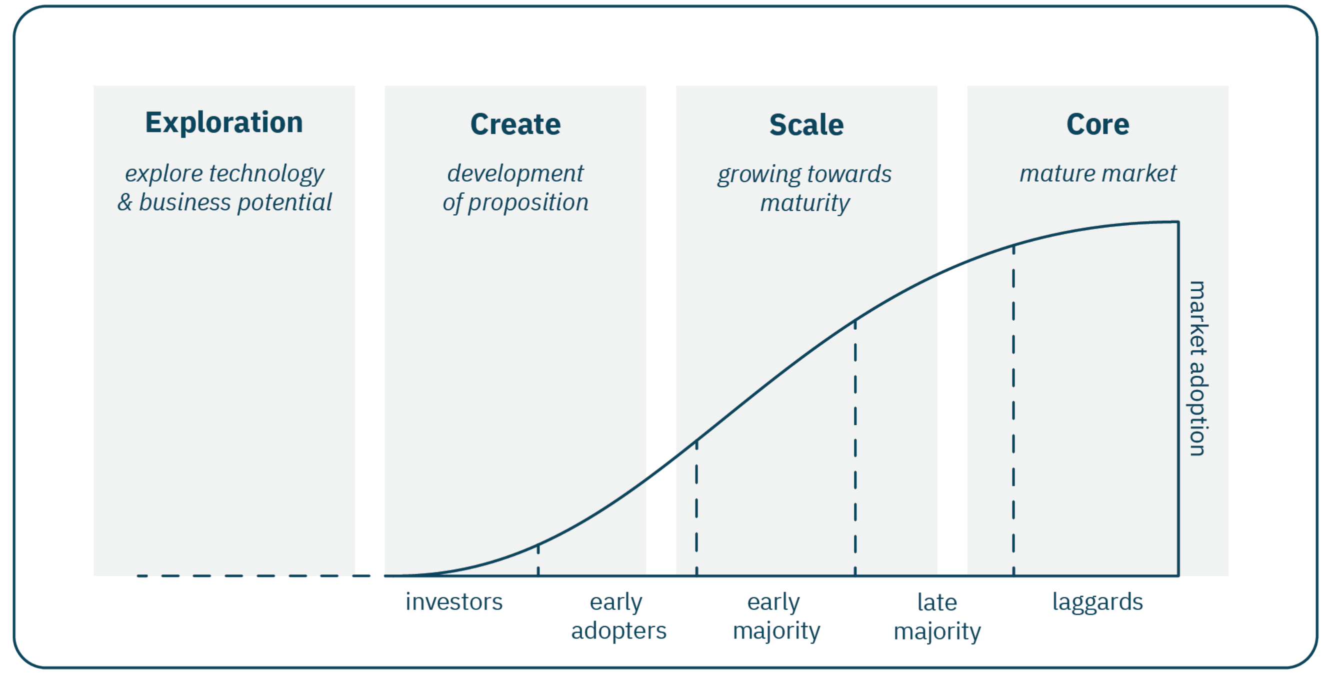


Figure 2.2.B – Stages of market adoption of propositions at Nedap. Adapted from Nedap N.V. (2023a, 2022).

Especially, as some of the previously mentioned concepts are somewhat ambiguous. A 7-point Likert scale was chosen as it can capture more precise and detailed information compared to the more common 5-point Likert scale. For the goal of the interviews, it was vital to not only get an understanding of the decision-making processes and levels themselves (and the development of uncertainty, impact, and frequency within these) but especially about the differences between the decision-making processes and levels. Hence, a more detailed scale will allow more easily to identify these differences. When applying a qualitative approach, the nuances in the interviewees' responses can be very important. As two of the three Likert scales used (i.e. 'uncertainty' and 'impact') are somewhat ambiguous (e.g. the definition of 'very high uncertainty' might differ among people), two rubrics have been created that explain the different intervals and provide examples, see Table A.3.B and A.3.C in Appendix A.3. These rubrics can also be used to help interpret the results.

Table 2.2.C - Overview of interviewees.

Function	Relevance to the interview goals
Head of Product	Member of the Management Team of the business unit. Experience with the entire product development process at the business unit & experience with strategic decision-making for product development within the respective business unit.
Business Controller	Member of the Management Team of the business unit. Experience with strategic decision-making for product development within the business unit & investment-related decision-making.
Market Solution Manager (Product Manager)	Experience with the entire product development process at the business unit & experience with the 'propositions' and 'products' decision-making levels.
Product Owner	Experience with new product development & experience with the 'products' and 'features' decision-making level.
Innovation Manager	Experience with new product development & experience with the 'propositions' and 'products' decision-making levels.
Agile Portfolio Management Consultant	Experience with agile working and the operational working structure (i.e. the way of working) of the organisation on all decision-making levels.
Product Design Lead and Team Lead	Experience with new product development & experience with the 'propositions' and 'products' decision-making levels.

In preparation for the interviews, an overview of the 'Innovation track' – the product development process of the Exploration team in Livestock Management – was created together with the Innovation Manager of the respective team. This process covers the 'Exploration' stage and a part of the 'Create' stage as presented in Figure 2.2.B. During the interviews, this overview could be used in addition to the thematic framework to provide an example or create a point of reference for the interviewee regarding the type of information that was asked for.

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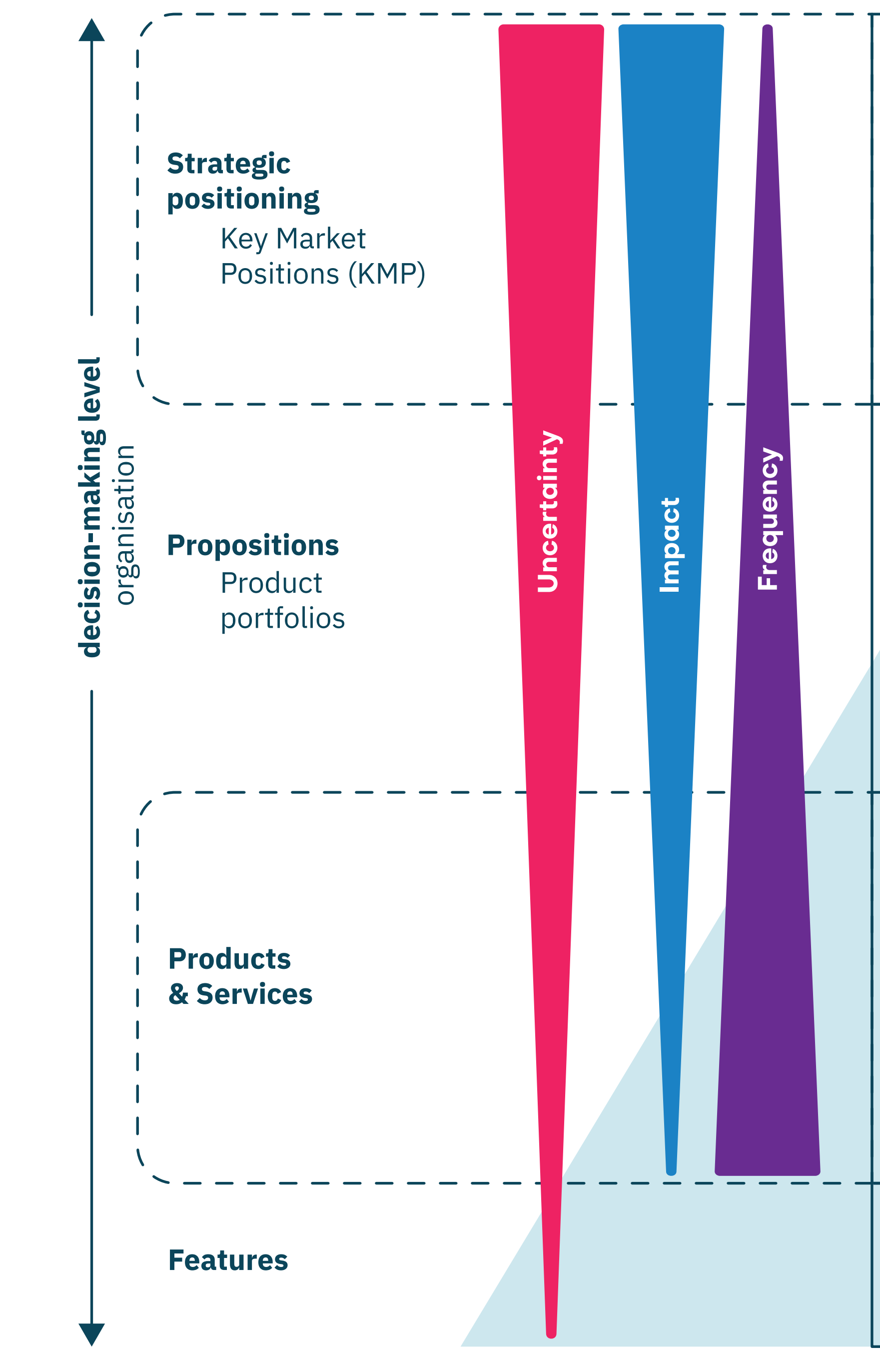
Decision-making level



Decision-making level	Uncertainty	Impact	Frequency	Decisions
Strategic positioning – Key Market Positions (KMP)	General uncertainty: **very high** Uncertainties concern questions such as: What is happening in the world around us, how is society, the market & technology developing, and what is our role in this? Are we able to find the right people for our team, and will our team capacity be sufficient? How will our financial position develop? **Critical uncertainty**: Is our assumption of the future market development true?	General impact: Business Controller: **major-severe** Head of Product: **moderate** The impact is dependant on the significance of the business unit and the proposition for the entire organisation. A higher significance also leads to a higher overall impact. Interestingly, strategy itself does usually not have a very strong (direct) impact. The origin of a defined strategy can often be found in 'best practices' and aims to create focus. However, a 'wrong' strategy can be disastrous for a company.	**Once a year**, the strategy is reflected upon/recalibrated. Around **every 2-3 years**, the entire strategy is reviewed.	**Crucial decisions**: For example the decision to cease development and production for a market (i.e. pigs). Once you have retrieved from a market, you cannot just re-enter. **Crucial events**: disruptive events, such as covid, materials scarcity, etc. **Management Team (MT) & board**
Propositions – Product portfolios	General uncertainty: **high** Uncertainties experienced are similar to those found at the strategic level. However, their strength is reduced, and the uncertainties are more 'operational' or 'actionable' of nature. If we choose to work on this (new) proposition, will we still be able to do our other work? **Critical assumption**: It is assumed the KMP strategy is of good quality.	General impact: Business Controller: **moderate-significant** Head of Product: **major** A proposition aims to put strategy into operation. Its quality (in focus, positioning, execution, etc.) can have a stronger (direct) positive or negative impact than a strategy decision.	The current progress of the propositions are reflected against the yearplanning and strategy **quarterly** in the portfolio review/planning. The large improvements/changes that should be worked on are dicussed here. **Once a year**, the strategy for the individual propositions are recalibrated. This is done simultaniously with the strategic positioning.	**Crucial decisions**: The **Market Solution Manager (MSM)** determines the WHY for the proposition. I.e. the direction for the proposition, fundamental technology, and business case. E.g. one time buy or subscription. This is crucial to its success. i.e. Why are we making something, and for whom? **MSM + Management Team (MT)**
Products & Services	General uncertainty: **moderate** The uncertainties encountered relate to the problem definition and the fit between the goals/problem of the client/stakeholders and the created solution. Also organisational uncertainties are experienced, such as work capacity of the organisation, workload, and project costs.	General impact: **minor** The impact mainly relates to the created workload or project costs/revenue, due to successful or unsuccessful product development. It is recognised that further in the development process this impact can grow (i.e. due to scaling).	On a **daily** to **(bi-)weekly** basis design-decisions for the development of the product are made (i.e. decisions in hardware or software configuration). **Quarterly**, the progress of the product development is reflected upon in the portfolio review/planning.	**Crucial decisions**: • Hardware; choosing a critical component, or a specific cofiguration for a technological solution. • Software; choosing server location (e.g. China, EU). A big investment to allow future growth. The **Product Owner (PO) + team** are responsible for the project operation itself. At the start & end **MSM** has more responsibility. For larger investments and strategy changes, the decisions are 'prepared' by the **PO (+team)** + **MSM**. The **MT** then makes the final decision.
Features	General uncertainty: **little**			The **PO + team** are responsible for the project operation itself.

Figure 2.2.D - Summary of the findings for each of the decision-making levels. On the left, the four different decision-making levels are shown. On the right, for each of the three parameters – uncertainty, impact and frequency – a summary of the findings per decision-making level is presented.

During the interviews, which lasted between 30 minutes and 1 hour and 30 minutes, the approach discussed below was handled. The order of these steps was important to guide the interviewee through the objectives of the interview and explain the concepts clearly before they were discussed.

1. Discussing the goal of the thesis and the interview. Next, the concept of uncertainty was explained as this is the main topic of this research and the interview;
2. Decide together with the interviewee what decision-making levels and/or product development processes to discuss. Followed by discussing and mapping out (drawing) the respective decision-making level(s) or product development process(es) and their main goals;
3. The concepts of impact and frequency were explained, after which the uncertainty, impact, and frequency for the respective decision-making level(s) or product development process(es) were mapped on the template (see Figure A.3.A in Appendix A.3). As part of the mapping process, 'labels' were created in the template to capture the rationale of the interviewee and examples provided to support their rationale. Here, the interviewee could also specify the type of uncertainty or impact encountered;
4. The concept of crucial decisions (or crucial decision-moments) was explained, after which these were added to the created overview.
5. The discussed results so far were reviewed again and the most important decision-makers within the product development process were indicated.

Findings

The findings of each of the interviews have been processed individually, after which an overview of the results has been created. The overview of the results is presented below

Overview of the results

The overview of the results, is represented in three figures, see Figure 2.2.D, 2.2.E, and 2.2.F. To help interpret the Likert scales for the degree of uncertainty, level of impact or frequency indicated, the rubrics (see Table A.3.B and A.3.C in Appendix A.3) can be used.

Open the fold-out page on the left to view **Figure 2.2.D**. Figure 2.2.E and 2.2.F can be found on the next page.

Figure 2.2.D shows a summary of the findings for each of the decision-making levels and focusses on the main differences between these levels for uncertainty, impact and frequency. Moreover, examples of crucial decisions are shown along with the most important decision-makers for each of the different levels. As can be seen, for the decision-making level 'features' little to no findings have been represented. Throughout the interviews, it was recognised the size of these projects is so small, that the development process of 'features' is taken up in the 'product' decision-making level instead. Hence, little to no data is available for this specific decision-making level and process.

Open this fold-out page on the right-bottom to view **Figure 2.2.E**.

Open the fold-out page on the right page to view **Figure 2.2.F**.

Figure 2.2.E and 2.2.F shows a summary of the results for each of the decision-making processes. Here, most detail in the development of uncertainty, impact and frequency throughout the 'propositions' and 'products' decision-making levels can be found. Not only were these processes most discussed in the interviews, but when discussed, the interviewees were also able to provide in-depth insights into these processes. For the 'strategic positioning' decision-making level the interviewees were able to provide general input about the uncertainty, impact and frequency. However, as the decision-making process only occurs every few years, it was not possible to provide detailed insight into the development of uncertainty, impact and frequency throughout the 'strategic positioning' decision-making process. In contrast, 'features' are developed more regularly. However, as discussed earlier, their development is taken up at the 'product' decision-making level. Hence, no data on the development of uncertainty, impact and frequency throughout this specific decision-making process is available either.

As quite some detail can be found in this part of the overview, the most important developments in uncertainty, impact and frequency throughout the decision-making processes will be discussed for each of the decision-making levels in Figure 2.2.E and 2.2.F.

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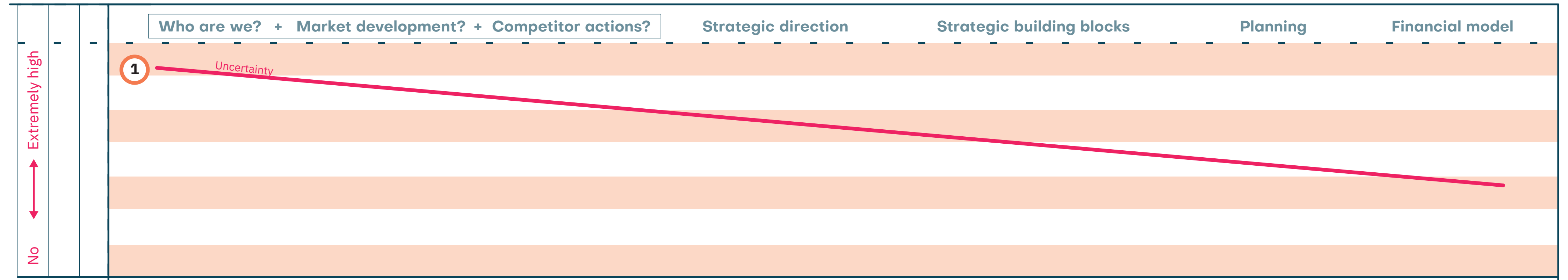
decision-making process
design/development process

Decision-making level x decision-making process

decision-making level
organisation

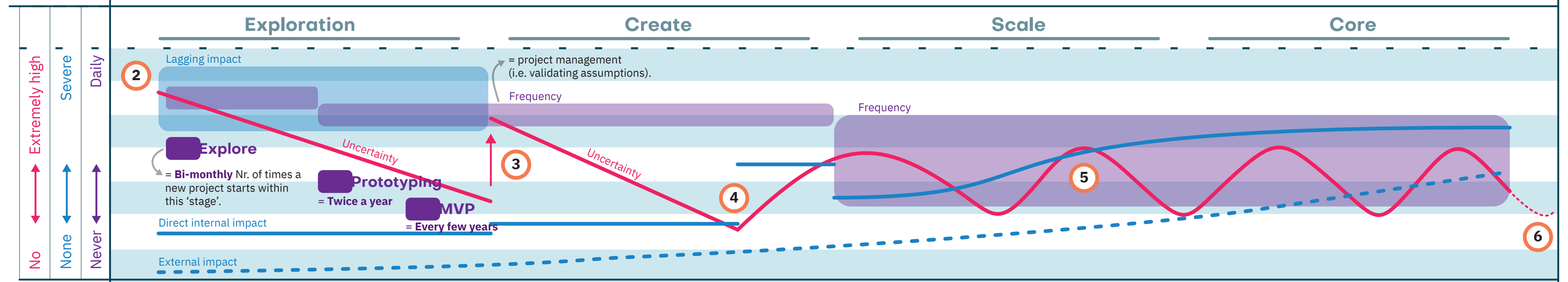
Strategic positioning
Key Market Positions (KMP)



Strategic positioning – The degree of 'uncertainty' is reduced throughout the process, however, it is not clear how the degree of ' uncertainty' develops throughout the process.

(1) At the start of the process a relatively high degree of 'uncertainty' can be encountered. The types of uncertainty are mostly related to #market (how is the market developing?) #technology (how is technology developing?) #culture&society (what is happening in society and what is our role in this?) #organisational (will our capacity and capabilities be sufficient?) #company strategy (what will our future financial position look like?). Although at the end of a strategic development process the degree of 'uncertainty' is reduced, it is not entirely removed. This can partly be explained by the level of detail a strategy concerns itself with.

Propositions
Product portfolios



Propositions – In this decision-making process, quite some fluctuations in the degree of 'uncertainty' throughout the process can be seen. In contrast, the development of 'impact' and 'frequency' throughout the process is more steady. In this overview, it can be recognised decision-making can also cause an increase in 'impact' and 'uncertainty'. This will be explained below.

(2) At the start of the process a very high degree of 'uncertainty' can be experienced. The types of uncertainty are mostly related to #market (what is the potential size of the market, and how much is the problem worth solving?) #technology (can we solve the problem?) #competitors (how can competitor actions influence our success?) #organisational. The 'frequency' in decision-making is quite high as the front-end of this process is fast-paced. The motto 'fail fast' also often emerges in different interviews. Whereas the direct internal and external 'impact' are very low (internal = minor, and external = none) – little investments are made, no organisational changes required, low organisational commitment and responsibilities – interviewees also identified a significant-severe 'lagging impact'. Meaning, decisions taken now (and sticking to these), can have a significant-severe 'impact' later on in the process (e.g. choosing a specific technology configuration or business case – one time buy or subscription – as the foundation of the solution).

(3) At the end of the Exploration phase, the MVP is launched and put into operation by the first few paying customers. Taking this step towards the creation of an actual product (i.e. solution) forces new assumptions and decisions to be made, causing the degree of 'uncertainty' to rise. The types of uncertainty are mostly related to #market (to what extent are the first customers representable for the entire market, is the majority of the market ready for this new product, and in what conditions should the market be for the product to be successful?) #technology and #usecontext (does the MVP function as a whole?) #culture&society (is the world ready for this new product?) #organisational (are we able to find the right people to further develop our product, and how should the team be constructed?). This step in greater commitment to the development of the product also causes the internal 'impact' to slightly rise, due to the organisational changes required for the development. The 'frequency' in decision-making does not significantly change.

(4) Towards the end of the Create phase, the 'uncertainty' is greatly reduced and the product is launched for the entire market. Causing a rise in both the degree of 'uncertainty' as well as the 'impact', due to organisational changes, investments and new commitments and responsibilities. The types of uncertainty are mostly related to #organisational (changing the way of working to accommodate for the product development).

(5) In transition from the Scale to Core phase, the product is fully embedded in the market. The 'uncertainty' will fluctuate throughout these phases, depending on external influences (e.g. competitors, changing regulations, material scarcity), events (e.g. global pandemic) and internal influences such as changing marketing strategies. The types of uncertainty are mostly related to #market #competitors #suppliers/partners #politics/regulations #environmental #culture&society (e.g. how will the outside world react to/engage with our product?). The 'impact' in these stages is significant. When events occur, or decisions are made, or changes occur, usually more people are involved, which can affect the way of working of the organisation, or the revenue. Moreover, also the external 'impact' increases, as the product is more and more embedded in the market and can create a higher impact here. The 'frequency' varies between bi-weekly and once a year. Important decisions (e.g. defining strategic scope) are made less often (i.e. once a year), and less important decisions (e.g. setting work priorities) are made more often (i.e. monthly). Most of the certainty in this stage can be found in the working structures of the organisation.

(6) Logically, the decision-making process does not end abruptly here. Only when all activities surrounding the proposition are ceased, the decision-making process related to the proposition will come to an end.

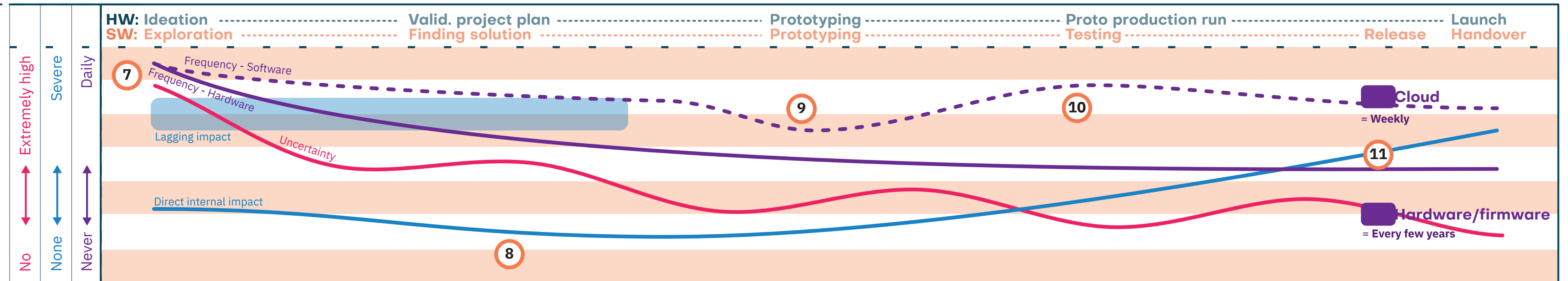
Figure 2.2.E - Summary of the results for each of the decision-making processes. On the left, the decision-making levels 'Strategic positioning' and 'Propositions' are shown. On the right, first, a graph is presented where the development of uncertainty, impact and frequency throughout the 'propositions' and 'products' decision-making levels can be found. Below each of the graphs, the most interesting developments (that are indicated with a number) are explained.

decision-making process
design/development process

Decision-making level x decision-making process

decision-making level
organisation

Products & Services



Products – In this decision-making process, the development of 'uncertainty', 'impact' and 'frequency' is quite steady. It should be noted, the development processes for both hardware and software have been combined in one overview, although these processes are vastly different. However, the development of 'uncertainty', 'impact' and 'frequency' is quite similar for both processes. The most important variations and developments will be explained below. In case the hardware and software development processes differ, this is indicated.

(7) At the start of this process a very high degree of 'uncertainty' can be experienced. The types of uncertainty are mostly related to #market (e.g. market relevance of solution) #technical (e.g. lead time) #usecontext #suppliers (e.g. future availability of critical components) #regulations (e.g. certification of components and products). Over time, the 'uncertainty' decreases. However, slight fluctuations can still be recognised, due to for example external influences or events. The direct internal 'impact' is minor/mild. For the start of the development, a team needs to be created. In case the request by e.g. management or the market solution manager turns out to be unrealistic, the strategy should (partly) be rethought, causing extra workload. Interviewees also identified a significant-major 'lagging impact'. Meaning, decisions taken now (and sticking to these), can have a significant-major 'impact' later on in the process (e.g. choosing a specific technology configuration or business case as the foundation of the solution). The 'frequency' is quite high, however, steadily reduces over time when the development process starts to find its place in the way of working of the organisation. Interestingly, the 'frequency' remains higher for software. The interviewees indicated the software development process is more fast-paced than hardware. The products can more quickly be tested, and there is no presence of production and delivery time for components.

(8) Further on in the process a slight dip in the direct internal 'impact' can be recognised. The workload is embedded into the way of working of the organisation, and not many changes are made.

(9) In the prototyping stage of software development a dip in the 'frequency' can be recognised. Prototyping is simply done on a slower interval rate that the other stages.

(10) In the testing stage of software development an increase in the 'frequency' can be recognised. Testing is usually done very often, and can be done very quickly and easily.

(11) Towards the end of the products process, the direct internal 'impact' increases. For hardware at launch, this relates to the organisational change required to facilitate further development and scaling of the product. At this moment, no technical uncertainty can be present. For software, this is more related to the aftercare (i.e. the operational work required to keep the product running).

Features

(12)

Features

(12) As the development of 'features' is taken up in the 'products' development process, no data on the development of 'uncertainty', 'impact' and 'frequency' throughout this specific decision-making process is available.

Legend

Uncertainty	Impact	Frequency
Extremely high	Severe	Daily
Very high	Major	Weekly
High	Significant	Monthly
Moderate	Moderate	Quarterly
Little	Mild	Once a year
Very little	Minor	Once every 2 to 5 years
No	None	Never

Figure 2.2.F - Summary of the results for each of the decision-making processes. On the left, the decision-making levels 'Products & Services' and 'Features' are shown. On the right, first, a graph is presented where the development of uncertainty, impact and frequency throughout the decision-making process can be found. Below each of the graphs, the most interesting developments (that are indicated with a number) are explained.

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Concluding the expert interviews

The goal of the interviews was to collect evidence to decide how an approach to cope with uncertainty in product development should be implemented at Nedap. Based on the previously discussed results, it can be recognised the highest degree of uncertainty can be encountered at the 'strategic positioning' decision-making level (see Figure 2.2.D). The highest level of impact can be found at both the 'strategic positioning' and the 'propositions' decision-making level. Finally, the highest frequency can be seen at the 'products' decision-making level. Following these conclusions, the optimum of the three parameters can be found at the 'propositions' decision-making level (see Figure 2.2.D). At this level, a high degree of uncertainty is present, the outcome of decisions has a high impact, and decision-making processes are executed relatively often. This implies that this level could benefit the most from the application of an approach to cope with uncertainty. However, this does not imply the other decision-making levels could not benefit from the approach, although perhaps in a slightly less beneficial way due to either a lower uncertainty, impact or frequency in the respective decision-making level.

When taking a closer look at the 'propositions' decision-making process, there are several moments within the development process where an optimum of the three parameters can be found.

- At the start of the Exploration phase; although not a high degree of direct internal or external impact can be encountered here, a very high degree of lagging impact can be recognised. Meaning, that decisions taken now (and sticking to these), can have a significant-severe impact later on in the process (e.g. choosing a specific technology configuration or business case – one-time buy or subscription – as the foundation of the solution).
- At the end of the Exploration phase/start of the Create phase; a large increase in uncertainty and a slight increase in direct internal impact can be seen.
- At the end of the Create phase; a large increase in both uncertainty and direct internal impact can be recognised.
- Within the Scale and Core phase; within these phases, a large increase in direct internal and external impact can be found, and a fluctuating degree of uncertainty.

Observing the 'products' decision-making process, an optimum of the three parameters can be found in the front-end part of the process, where a very high degree of uncertainty and a significant-major lagging impact can be found.

When comparing these results to the literature presented, one striking difference can be recognised. Jetter (2003) shows how the uncertainty in the product development process and product life cycle fluctuates, however, also gradually reduces over time. In the findings of these interviews, within the 'propositions' decision-making process, the uncertainty fluctuates as well, however, does not reduce over time. This could imply that not only the fuzzy front end of product development could benefit from an approach to cope with uncertainty but also other phases later in the product development process.

Limitations

Although the interviews provide a more in-depth understanding of the degree of uncertainty, impact and frequency encountered within the different decision-making levels, and the development of the three parameters throughout these processes, when evaluating the results several limitations can be recognised. Firstly, the number of interviewees only forms a small sample group. Hence, it is difficult to make generalised conclusions about the different decision-making levels and processes in product development. Ideally, more interviewees would have been included for each of the different decision-making levels and processes to help verify the information obtained. Currently, one or two interviewees were interviewed for each of the decision-making levels and processes. Next to obtaining better-verified results, this could potentially also have given more detailed knowledge into the 'strategic positioning' decision-making process, which currently lacks detailed insight. Lastly, in the interviews, the interviewees discussed their perception of the degree to which the three parameters were experienced. The actual degree in which these are present (e.g. the degree of uncertainty) in the different decision-making levels and processes could differ from their discussed perception. Although tools were made (i.e. uncertainty rubrics, template) to create one scale to measure the uncertainty and prevent this bias, this could explain the difference between the results of the interview and the discussed literature.

2.3 Concluding the preliminary research

The preliminary research investigated uncertainty in product development through a literature review and examining the product development process at Nedap in several interviews. This research helped to get a better understanding of what uncertainty is, why uncertainty should be considered, and how uncertainty can be coped with in the decision-making process of product development.

Overall, uncertainty creates a negative impact on the product development process by impeding the quality of design-decisions made. It is important designers are able to control uncertainty to reduce its negative impact. Not only is uncertainty distinctive for product development, it also prevails and fluctuates throughout the entire product development process and product life cycle. Especially in the fuzzy front-end of product development a high degree of uncertainty can be identified and the decisions made here largely determine the costs, quality and time frame of development projects. Therefore, the fuzzy front end could benefit the most from the application of an approach to cope with uncertainty.

Different existing approaches are available to cope with uncertainty, each with its own possible added value and drawbacks to the design of an approach to cope with uncertainty. Important elements that need to be considered for the design of the approach are presented next. The four stages of the uncertainty management approach by Hillson (1997) and Kutsch & Hall (2009) can be used to provide a foundation for the design; planning, identification, analysis, and response. The work by Lasso et al. (2020) emphasised the importance of responding to the nature of uncertainty in NPD and how investigating this nature can help in determining how to cope with it. On one side this helps in identifying the level of influence the designer or the organisation has over the uncertainty and on the other side can support selecting suitable coping approaches. Hence, it is essential the design can aid in identification of uncertainty and the source(s) from which uncertainty is emerging. The levels of uncertainty by Courtney et al. (1997) can be integrated into the design to help tailor the provided tools and techniques more specifically to the innovation project, based on the specific level of uncertainty. Simulation and scenario techniques can be used in the design to examine uncertainty more in-depth, especially when a high level of uncertainty is experienced in the innovation project. Lastly, the learning plan by Rice et al. (2008) can be used to help integrate the design and its application into the organisation.

The research by Hillson (1997) and Terje Karlsen (2011) introduced four attributes that are essential in assessing the maturity level of an organisation in managing uncertainty; process, application, experience, and culture. Although each of these attributes is important, without available uncertainty management processes for the organisation, it becomes fairly difficult to establish the other attributes. Hence, primarily, a method, rather than a more generic approach, that provides steps or guidelines to structure this process for product development in the organisation is needed before the other attributes can be fully addressed.

Following the conclusions, applying a method to cope with uncertainty can help Nedap to foremost gain more control over uncertainty in product development and secondly reduce the uncertainty. Not only could this help in creating more successful products, but it could potentially also help in reducing the costs and time frame of the product development project when uncertainty is reduced in the front-end of the development process. Moreover, actively coping with uncertainty in team form through a learning trajectory can enhance the working culture within an organisation to support innovation.

chapter 3
Requirements

The synthesis from the preliminary research is used to shape the requirements. These are formulated through 1) a stated purpose (i.e. brief statement that summarizes the goals of the method), 2) a description of the use context (that illustrates in what different situations the method is intended to be used), and 3) functional requirements (which describes in more detail what the method should comply with). This structure is chosen to clearly express the goals of the design and provide a strong foundation for the design process. In this context, the requirements provided direction and focus to the development process of the method. Moreover, the structure can also be used to evaluate the final method by providing specific functional requirements that can better be evaluated than the more abstract main goals they represent.

The functional requirements have been structured into two domains; knowledge generation and usability. 'Knowledge generation' expresses the need for the method to contribute to the development of product design knowledge that aids the product development process, and ensures there is a learning moment when working with the method (Eger et al., 2013). 'Usability' states the requirements for 'ease of use' and proper integration of the method into the product development process at Nedap. As discussed in the preliminary research, the method must not only provide steps or guidelines to structure the uncertainty analysis process, it should also be properly integrated into the organisation to contribute to its maturity level in managing uncertainty. Good usability and applicability of the method can help in this.

Stated purpose
For the design case, a method needs to be developed to aid the decision-making process for product development at Nedap to cope with uncertainties. This method should enable the identification and analysis of uncertainties and their potential impact on (future) product development. Subsequently, it should aid in the selection of (a) suitable approach(es) to deal with the uncertainty. Next to this, the method should aid in exploring (future) challenges to examine the potential relationship between these challenges and product development and identify accompanying opportunities and risks.

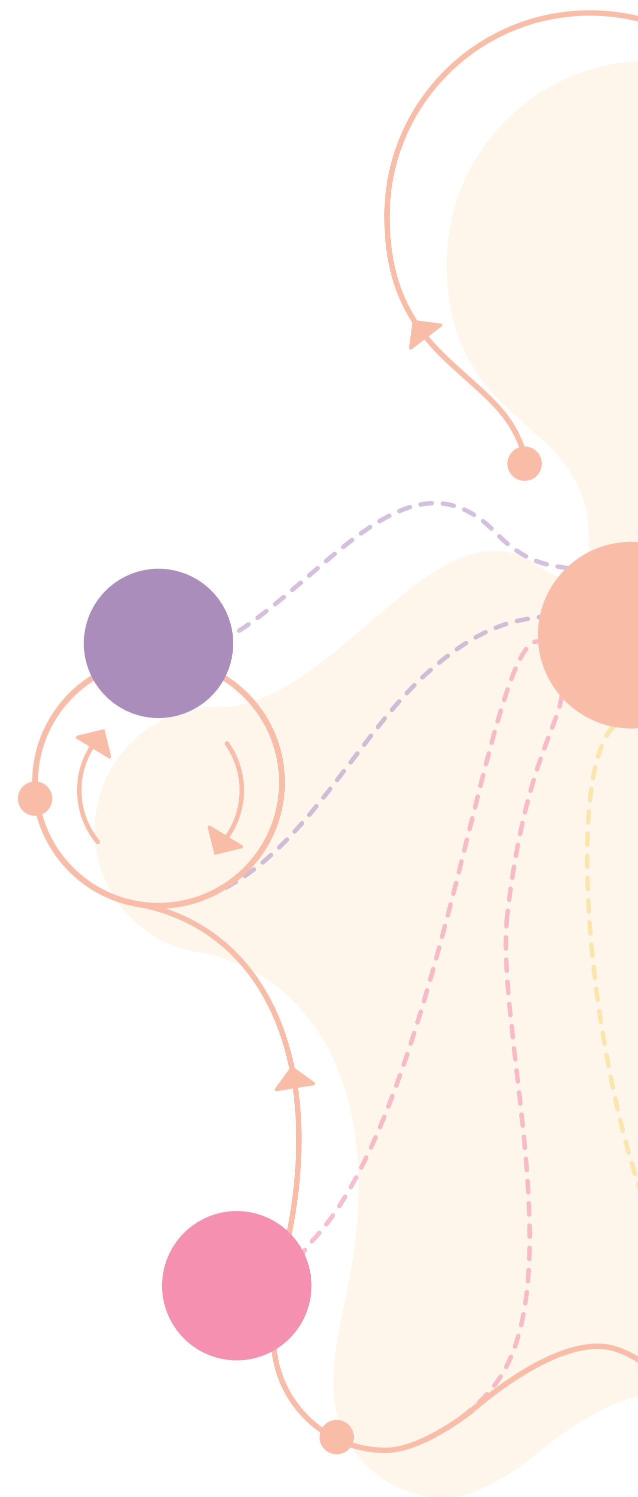
Use context
To shape the requirements for the design of the method, the synthesis from the preliminary research has been used to frame the use context of the method by describing several possible use cases. This scope will allow for setting more specific requirements to provide direction and focus to the design process and evaluate the design. Moreover, the use context will also help to select an appropriate design project for the evaluation of the method.

In the first use case, the method has been embedded into the organisational planning and work cycle, such as a specific milestone within the fuzzy front end of the product development process. This part of the development process can benefit the most from the application of a method. The second use case is action-based, where the execution of the method is triggered by specific actions that are (planned) to be done. The expert interviews showed that changes in the product development process, such as enlarging the development team or launching the product can greatly increase the uncertainty. The third use case is problem-based, where the method is executed when certain problems or difficulties are experienced. As uncertainty can make design activities more challenging, coping with the uncertainty could help deal with the problem. The fourth and last used case is event-based, where the execution of the method is triggered by certain events or developments that take place. In the expert interviews can be seen how for example changing strategies of competitors can increase the uncertainty.

- Workflow-based use case: During the fuzzy front end of product development (i.e. at the end of the 'exploration' stage or the start of the 'create' stage in proposition development at Nedap, see chapter 2.2 Expert Interviews) the method is used as a reflection tool to support decision-making regarding the focus of the development activities and deliver input. Here, the use case is embedded into the organisational planning and working cycle.
- Action-based use case: Before large investments are made, the method is used to support decision-making. For example, deciding to take over another company to foster product development or the acquisition of specific technology.
- Problem-based use case: When uncertainty-related difficulties are experienced in the development, or the development team gets stuck, the method is used to analyse the problems and find a solution direction or select development activities. For example, the envisioned product concept or solution seems unfeasible.
- Event-based use case: When external influences are changing or appear to be changing, the method is used to examine and monitor the changing landscape of operation. For example, developments such as ChatGPT, or the Covid pandemic.

Functional requirements, the method should…

1. **Knowledge generation**
    a. …aid identification of uncertainties
        i. *This requirement relates to the broad spectrum of uncertainty identification as described in the section 'what is uncertainty?': such as known uncertainties, unknown uncertainties, the source(s) from which uncertainty is emerging, and the degree in which certain uncertainties are experienced.*
    b. …support scanning of external developments and identify their relation to the product development
    c. …aid in examining the potential impact of uncertainties on product development
    d. …aid in exploring future challenges and identifying accompanying opportunities and risks
    e. …aid in selecting approaches to cope with the identified uncertainty
    f. …help in identifying crucial decisions
2. **Usability**
    a. …increase the ability of designers to control uncertainty
        i. *This requirement relates to the skills or proficiency of the designer required to deal with uncertainty. Enabling them to apply a certain level of control, providing them the power to influence or direct the course of events to a certain extend.*
    b. …be suited to the product development process of Nedap
    c. …be clear how and when to use the method in the product development process
    d. …provide structure to the process of exploring uncertainties
        i. *This requirement relates to providing structure in working with the high degree of vagueness and amorphousness that is characteristic of uncertainty.*
    e. …guide the users through the uncertainty analysis process
        i. *This requirement relates to the usability of the method in the product development process by employees of Nedap.*
    f. …be suited to the decision-making process of Nedap
        i. *This requirement relates to how decisions are made for product development at Nedap.*



chapter 4

Design & evaluation process

In this section, the design and evaluation process is introduced which is structured into three design cycles. Next to this, also the overall design rationale will be discussed that underpins the general design-choices that have been made. Within each design cycle itself, the more detailed design-choices will be addressed.

To design a method to aid the decision-making process for product development at Nedap to cope with uncertainty, an iterative design approach – that is characteristic of product development – has been adopted (see Figure 4.A). Such an approach describes the design process as a reoccurring sequence of steps. In between these sequences, the obtained results are compared to the desired results and the conclusions or learnings will be looped back into the next sequence. This iterative design approach addresses the complex relationship between product functions and requirements. “One is not purely dependant on the other, but there is a clear mutual influence” (Eger et al., 2013, p.228). As the problem described is complex, subject to vagueness (e.g. characteristic to uncertainty), requires a good theoretical understanding but also needs investigation of practical application, a design approach that facilitates this learning process is required. This iterative process of reoccurring sequences is finished when the evaluation concludes the design as acceptable.

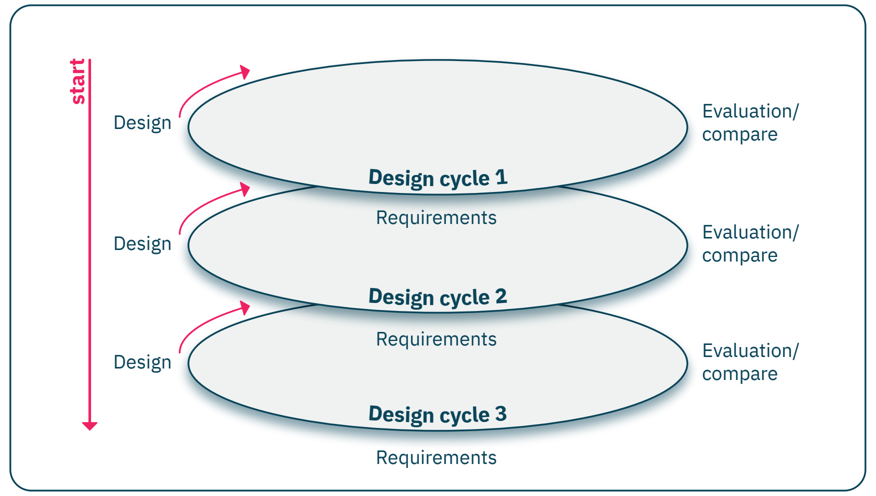


Figure 4.A – Iterative design approach. Adapted from Eger et al. (2013).

In Figure 4.B (open the fold-out page on the right), an overview of the design and evaluation process is presented. Here, the most important developments and conclusions that shaped the design of the method are shown. Each of the design chapters is structured in a similar fashion to the blue building blocks on the left side of the figure. Logically, these chapters will also elaborate on the information discussed here. The right-most block ‘Outcome of this design cycle’ in the figure presents the most relevant conclusions that either shaped the next design cycle or concluded the design process altogether as the method was evaluated as acceptable.

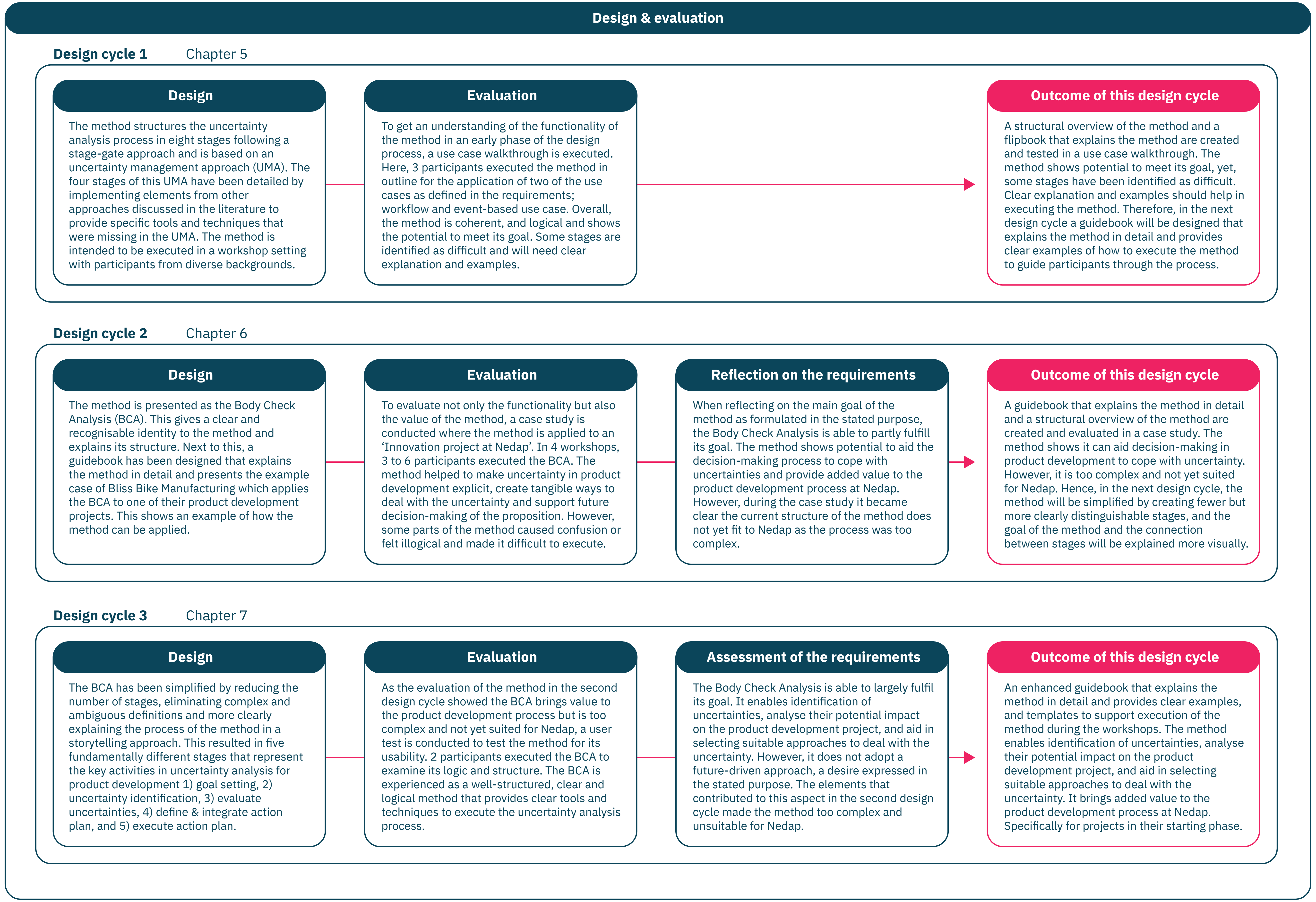


Figure 4.B – Overview of the design and evaluation process.

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In the second design cycle, an interesting development can be recognised. Here, for the first time, both the functionality and the added value of the method to product development at Nedap are assessed in a case study. Although the evaluation shows the method can aid the decision-making process in product development to cope with uncertainty, which is the main goal of the design, it also shows the method is not yet acceptable. The iterative design approach learned that merely translating all stated requirements into the method did not lead to an acceptable design. Instead, fulfilling the requirement 'Aid in exploring future challenges and identifying accompanying opportunities and risks' (i.e. the scenario-planning element of the method[3]) impeded the overall functioning of the method in the applied use context at Nedap. This brings the challenge of whether to 1) design a generic method to cope with uncertainty in product development, or to 2) design a method more specifically to product development at Nedap. As the iterative design approach shows, the evaluation element is vital to understanding the quality of the design. Without this element, the quality cannot be assessed regardless of the choice of whether to design for challenge 1) or 2). Hence, in the third design cycle, the focus shifted more towards designing specifically for the product development process at Nedap as this would provide the option to assess the quality of the method in both the functionality and value aspect.

[3] As presented in the research about simulation and scenario planning but also incorporated into the theory of the levels of uncertainty by Courtney et al. (1997), Helmrich & Chester (2022) and Vries, de & Toet (2022).

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chapter 5

First design cycle

This chapter presents the first design cycle. In the first design cycle, the preliminary research and the requirements are used as input for the design. First, the designed method will be introduced and the design-choices made in this design cycle are discussed. Thereafter, the evaluation of the design is presented.

5.1 Introducing the design

The developed method structures the uncertainty analysis process in eight stages following a stage-gate approach. The method focusses on guiding designers and decision-makers in product development through the process of uncertainty analysis to help them cope with uncertainty. A structural overview of the method can be found in Figure 5.1.A (open the fold-out page on the right page). This overview explains the structure of the method and how the different stages and gates are connected. Each of the stages focuses on a key activity in the process of uncertainty analysis and specifies concrete activities or techniques that should be executed in the analysis process. In addition to the visual overview, a flipbook explains each of these stages in more detail and can be used as a guide when executing the uncertainty analysis. The flipbook can be found in Appendix A.4.

The method is intended to be used in a group setting with participants from diverse backgrounds and expertise, apart from the members of the product development team itself. Inspired by the 'remarkable people' as discussed in the research of Bradfield et al. (2005), bringing in people with new knowledge will help to stimulate and challenge the thinking of the group to create a more comprehensive overview of identified uncertainties and create stronger scenarios.

The basis of the method can be found in the uncertainty management approach as discussed by Hillson (1997) and Terje Karlsen (2011). This approach provides a good general structure for the uncertainty analysis process. However, it does not yet give guidance on the specific techniques and tools that should be used. Hence, the four different stages (i.e. planning, identification, analysis and response) have been detailed by implementing elements from other approaches to cope with uncertainty to provide more specific tools and techniques that can be used in the analysis process. As discussed, this resulted in an eight-stage method. In Table 5.1.B an overview of the method in comparison with the uncertainty management approach by Hillson (1997) and Terje Karlsen (2011) is presented. The stage-gate approach is used to help assess the quality of execution of the method and help understand whether the uncertainty analysis is on the right track. When stages are poorly executed, this problem is identified early on and can be addressed before the uncertainty analysis is continued. Moreover, the gates help to maintain focus throughout the process by continuously reflecting on the objectives set in the design brief.

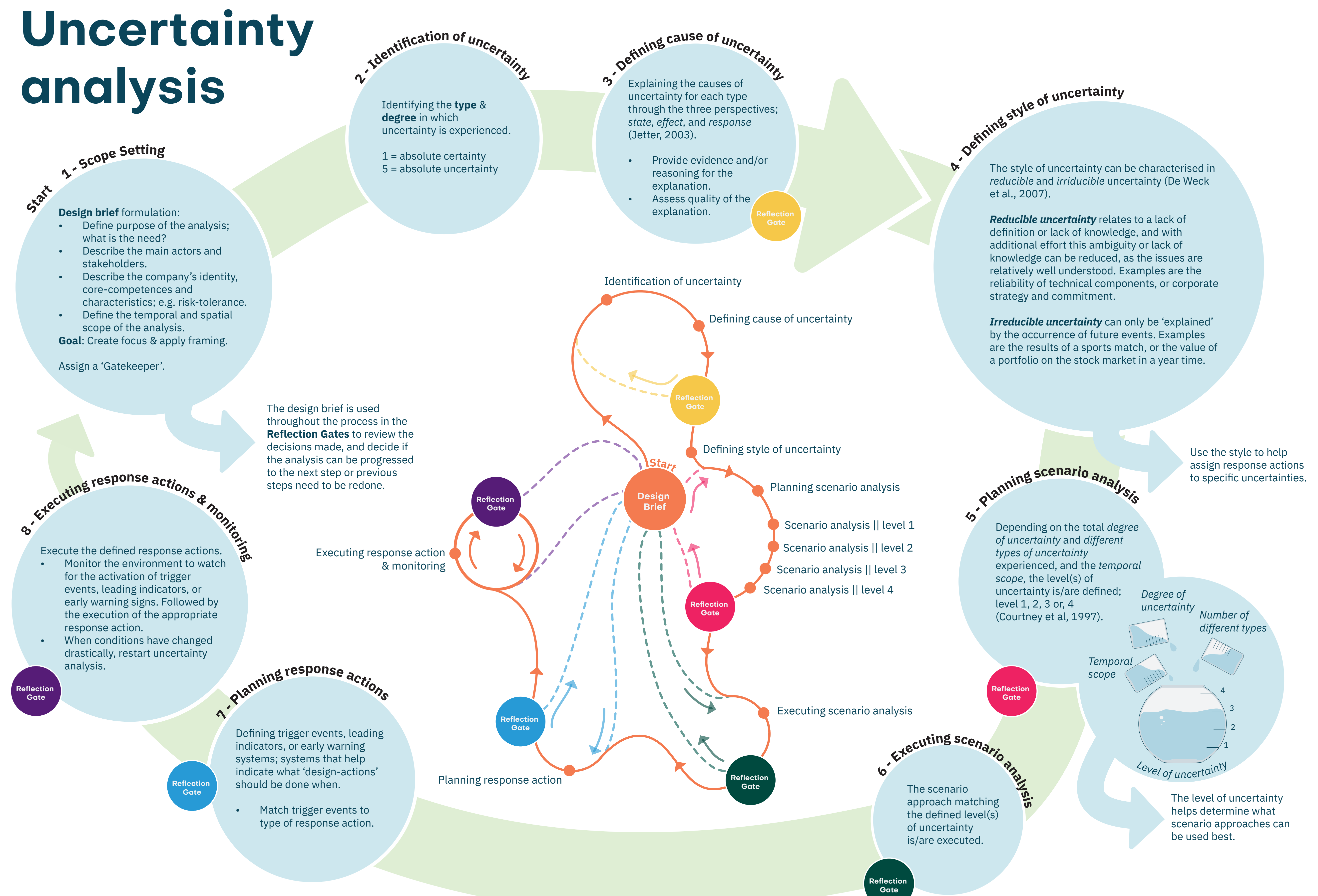

Figure 5.1.A – Structural overview of the method.

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A gatekeeper is assigned at stage 1 to ensure fair and high-quality evaluation during the process. They are responsible for evaluating together with the team whether a reflection gate can be passed or not. The different stages of the method and the reflection gates are addressed below.

Table 5.1.B - Overview of the uncertainty analysis method in comparison with the uncertainty management approach by Hillson (1997) and Terje Karlsen (2011).

Stage	**Uncertainty analysis method**	**Uncertainty management approach** by Hillson (1997) and Terje Karlsen (2011)
1	Scope setting	Planning
2	Identification of uncertainty	Identification
3	Defining cause of uncertainty	
4	Defining style of uncertainty	
5	Planning scenario analysis	Analysis
6	Executing scenario analysis	
7	Planning response actions	Response
8	Executing response actions & monitoring	-

Stage 1 - Scope setting
This stage aims to create focus and apply framing to the analysis. Setting clear objectives in the form of a design brief will help to maintain focus throughout the analysis process. The design brief should at least present the following elements:

- Purpose of the analysis. A reflection on the need to execute the analysis in the first place.
- Main actors and stakeholders. These will support the uncertainty identification by investigating all the actors related to the development of the product development project.
- Company's identity, core competencies, and specifically its risk-tolerance for the specific product development project. When planning the response actions in stage 7, this will help to identify what actions, and their related risk-level, are suitable for the company.
- Temporal (i.e. time-frame) and spatial (i.e. geographical-frame) scope of the analysis. These will help to define boundaries for the uncertainty identification and the scenario analysis.

At the end of this stage, the gatekeeper is assigned as discussed in the previous section.

Stage 2 - Identification of uncertainty
Identifying uncertainty is an important and difficult process in uncertainty analysis. The different shapes uncertainty can have (i.e. known, unknown or residual), make identification of uncertainty prone to incompleteness. If executed poorly, it can give a false sense of security as also addressed by Lipshitz & Strauss (1997). Hence, a tool has been created to support this process; the wheel of uncertainty. This tool provides an overview of thirteen different types of uncertainties that can be distinguished in product development, see Figure 5.1.C. These thirteen types of uncertainty are based on the sources of uncertainty as discussed in the preliminary research. Next to this, it allows to determine how strongly certain types of uncertainty are experienced by indicating the degree of uncertainty on a 5-point scale. Doing this will help decide in the succeeding stages what uncertainty analysis activities are appropriate to execute for the specific project (stage 5). The 5-point scale has been chosen as it allows for detailed differentiation between the different degrees and types of uncertainties. Defining the degree of uncertainty can help in determining the level of uncertainty by Courtney et al. (1997) (level 1, 2, 3 or 4) in stage 5. However, no direct correlation between these two scales exists, hence, the scale to determine the degree of uncertainty needs to be different.

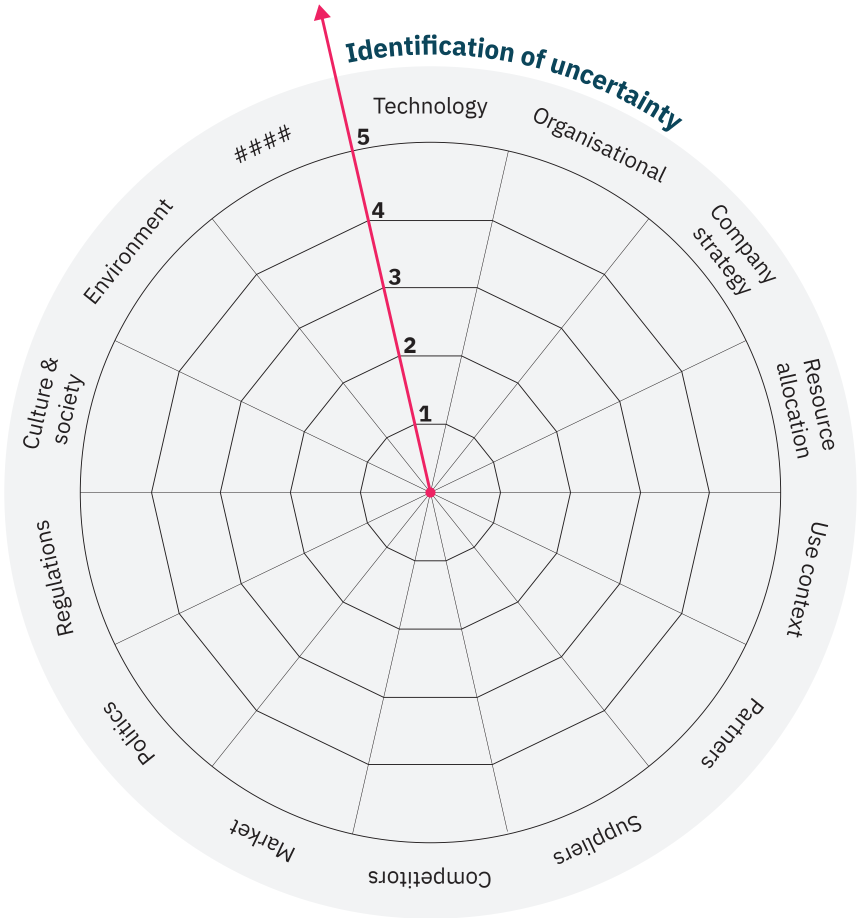

Figure 5.1.C – The wheel of uncertainty.

Stage 3 - Defining cause of uncertainty
This stage aims to verify and check the responses provided in stage 2. As discussed, uncertainty identification is prone to incompleteness, hence it is important to check the quality and completeness of the identified uncertainty. The theory by Jetter (2003) on the causes of uncertainty is used (i.e. state, effect and response uncertainty). Instead of making uncertainty explicit (as is done in stage 2), the cause for each of the thirteen types of uncertainty is explained. Here, participants are challenged to switch their perspectives and test their understanding of each of the different types of uncertainty. Their level of understanding is again mapped on the wheel of uncertainty.

> _Reflection gate_: In this reflection gate the work of stage 3 is compared to stage 2. A high understanding of a type of uncertainty in stage 3, should match with a low degree of uncertainty (i.e. high certainty) on the same type of uncertainty and vice versa. This way, participants can be sure about the completeness and quality of their uncertainty identification and can continue with the analysis.

Stage 4 - Defining style of uncertainty
To support the upcoming analysis and response processes, the style of the identified uncertainties is defined and characterized as reducible or irreducible uncertainty (De Weck et al., 2007). This categorization will help in determining which uncertainties need to be further analysed for their development or implications (i.e. irreducible uncertainties), and which can relatively concretely be addressed when planning response actions (i.e. reducible uncertainties).

Stage 5 - Planning scenario analysis
To ensure appropriate tools and techniques are applied to cope with uncertainty in the project, in this stage, the level of uncertainty is determined as presented by Courtney et al. (1997), Helmrich & Chester (2022) and Vries, de & Toet (2022). The level of uncertainty is determined by reviewing the degree of uncertainty, the different types of uncertainty (both from the uncertainty identification in stage 2) and the temporal scope (from the design brief in stage 1). Each of the levels (level 1, 2, 3 or 4) will present different suitable approaches to analyse and cope with the identified uncertainty.

> _Reflection gate_: In this reflection gate the identified level of uncertainty and the accompanying analysis are compared to the design brief and the purpose of the uncertainty analysis. It is important to review whether the selected analysis tool and techniques will help in reaching the objective of the uncertainty analysis.

Stage 6 - Executing scenario analysis
In this stage, the selected analysis tools and techniques are executed.

> _Reflection gate_: After completion of the analysis, the executed analysis is reflected upon to determine whether it generated the required knowledge to answer the questions set in the design brief and helps in reaching the objective of the uncertainty analysis.

Stage 7 - Planning response actions
After analysing the uncertainties and evaluating their consequences, the response actions can be planned. In case a level 2, 3 or 4 uncertainty was identified in stage 5, this is done by creating an early warning system based on the executed analysis as presented in the work by Vries, de & Toet (2022). The focus of this system lies in defining a monitoring approach to observe the development of identified uncertainties and assigning response actions to specific possible developments. The goal is to determine when and what design-actions need to be done. The early warning system will help by guiding this process. For a level 1 uncertainty, an early warning system is not required and any actions can directly be executed as the uncertainty experienced is too low.

> _Reflection gate_: In this reflection gate the coherency, workability and integration into the way of working of the organisation of the early warning system is evaluated. Moreover, the defined response actions are reflected upon to determine whether they match the purpose of the analysis and will help in reaching the objective of the uncertainty analysis.

Stage 8 - Executing response actions & monitoring
In this stage, the created early warning system is deployed and the response actions are executed. An important part of this stage is monitoring, where the environment is observed to watch for developments or changes matching the early warning system and what assigned response actions should be executed.

> _Reflection gate_: In this reflection gate the effectiveness of the response actions with respect to the purpose of the analysis as defined in the design brief is evaluated. Moreover, the validity of the created early warning system and the defined response actions, considering changing conditions, is reflected upon. This will help determine whether (a part) of the uncertainty analysis should be redone to obtain an up-to-date and effective early warning system and response actions.

5.2 Evaluating the design Use case walkthrough

The goal of the evaluation is to investigate the functionality of the method on a global level to get an understanding of the functionality of the method in an early phase of the design process. This means that the individual stages of the method were not executed in full detail or were only executed partly. Focus is here applied to the relevance of the different stages of the method, the coherence between these stages, and whether the method would potentially be able to meet its goal: to aid the decision-making process in product development at Nedap to cope with uncertainties. The evaluation will be used as input for the second design cycle of this thesis.

Method
The method will discuss the overall set-up and structure of the evaluation.

Set-up of the evaluation
The evaluation is executed in three sessions of 1 hour and 30 minutes, where in each session a different participant executed the method in outline. For the application, two different use cases have been selected, based on the intended use context as described in chapter 3 Requirements. These use cases where an 'Innovation project at Nedap' (workflow-based use case) and 'ChatGPT' (event-based use case). An overview of the different participants and the use cases they executed during the sessions can be found in Table 5.2.A.

Workflow-based use case: Innovation project at Nedap
The exact details of this project are confidential. The project is distinctive due to a high degree of uncertainty, as a technology that is new for Nedap and users of Nedap products is developed for one of their existing markets. The product is developed by the Exploration Team (i.e. innovation team) in collaboration with an external knowledge partner. At the time of the evaluation, the project is at the end of the 'exploration' phase in the fuzzy front-end of the product development process.

Event-based use case: ChatGPT
Rapid developments in machine learning and the adoption of the technology in generative tools (e.g. ChatGPT, Stable Diffusion, Midjourney, etc.), show new and strong capabilities of AI. These developments could potentially influence how products are created, or change the way work is done at Nedap. It is important to explore the impact these developments have on product development.

Table 5.2.A – Overview of the different participants and the use cases they executed.

Participant	Role within Nedap	Use case
Participant 1	Master's graduation student Industrial Design Engineering	Chat GPT
Participant 2	Innovation Manager	Innovation project at Nedap
Participant 3	Market researcher	Innovation project at Nedap

Structure of the evaluation
Each of the sessions was executed following a similar structure:
Introduction: The session started with an introduction, where the goal of the thesis and the use case walkthrough were explained. Thereafter, the method and the different stages were introduced.
Body: During the main part of the session the participants executed the method. For this part of the session, a visual overview was provided that explains the different stages and how these are connected (see Figure 5.2.B). In addition, a flipbook was given that explains each of the stages and the reflection gates in more detail (see Figure 5.2.B and Appendix A.4).
Closing: At the end of each session, the participant and the researcher together went over the created work while the participant discussed their experiences.

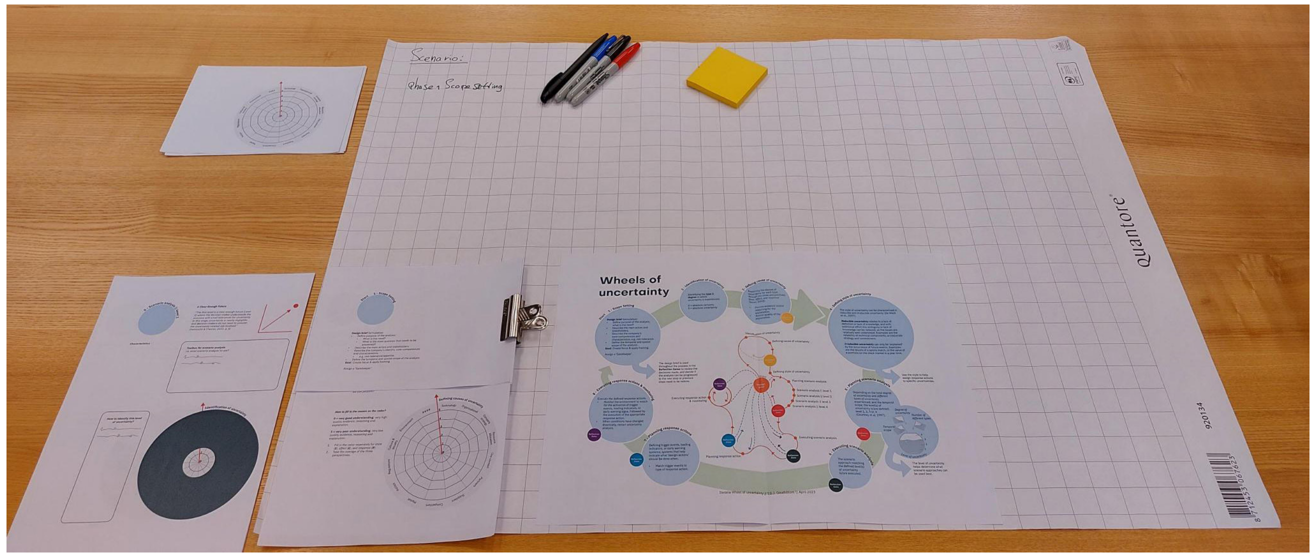

Figure 5.2.B – Picture of the use case walkthrough set-up. In the left lower corner the flipbook can be seen. In the centre of the figure, a visual overview of the uncertainty analysis method can be found.

Data collection
The use case walkthrough is evaluated through observation and a semi-structured discussion. These qualitative forms of data collection fit well with the experimental and explorative part of this research and allowed to explore specific responses further. Moreover, they are relatively easy and time-efficient to prepare, which is important for the goal of this evaluation as discussed earlier. The observation was overt (i.e. the participants knew they were being observed) and direct (i.e. watching the behaviour, interactions and events as they occurred during the session). Next to direct, indirect observation (i.e. watching the results of behaviour, interactions and events after the session) was applied. For the last-mentioned, the created materials and delivered work were observed.

During the session, the participants were asked to make the assumptions they were making explicit and think out loud. The researcher took notes on their thought process, feedback, responses and overall progress. After completion of the method, there was a semi-structured discussion where the created work was discussed and the participant shared their experiences. The focus of this discussion was on the relevance of the different stages of the method, the coherence between these stages, and whether the method would potentially be able to meet its goal. Next to this, the participants were also asked what parts of the method they found unclear or incomplete (and how this could be improved from their perspective), and what parts of the method they found very strong. A summary and conclusion of the findings of the use case walkthrough can be found in the next section: Concluding the use case walkthrough. Here, the most important elements that shaped the design of the method, and influenced the second design cycle, are presented.

Concluding the use case walkthrough

The goal of the evaluation was to investigate the functionality of the method on a global level to get an understanding of the functionality of the method in an early phase of the design process. The conclusion of this use case walkthrough will be used as input for the second design cycle.

When reflecting on the functionality of the method during the use case walkthroughs, participants were positive. Already during the short sessions, clear implications could be found for the product development process. The method was logical and provided a clear structure for the uncertainty analysis process. Overall, the different stages of the method were coherent, relevant and showed potential to meet the goal of the method: to aid the decision-making process in product development at Nedap to cope with uncertainties.

During the sessions, it could be recognised the first stage ‘scope setting’ was vital to the process. Having a clear design brief will help to critically reflect on the progress when executing the method and is important for the quality of the reflection in the reflection gates. When working on the second stage ‘identification of uncertainty’, some participants had difficulties with distinguishing and interpreting the different types of uncertainties. Moreover, they recognised that the uncertainties can be dependant on one another and can influence each other as well. The most difficult part of the method could be found in stage 3 ‘defining causes of uncertainty’. However, the importance of this stage was recognised by the participants. This difficulty was mainly caused by the complexity of the stage. In addition, it was recognised the terminology used in the method potentially adds to this complexity. The differences between the terms used (e.g. type, degree, and level of uncertainty) should be made more clear, and the provided definitions in the booklet should be made more explicit. For example, by providing a clear overview of the different types of uncertainties and their definitions. This will make it easier to determine the type and degree of uncertainty. For stage 4 ‘defining style of uncertainty’, the importance of integrating the outcome of the stage into defining response actions in stage 7 ‘planning response actions’ was highlighted. Also stage 5 ‘planning scenario analysis’ was described as a crucial point in the analysis where the method builds up to the first 4 stages. This stage largely determines how the analysis process continues from here on. Although the method shows potential to meet its goal, the challenge to safeguard the accessibility of the method is highlighted. When working with the method, the relevance of the different stages and their goals should be clear.

Finally, in reflection on the two use cases chosen for the use case walkthrough, it could be recognised that the method was easier to apply to the workflow-based use case (i.e. the Innovation project at Nedap) compared to the event-based use case (i.e. ChatGPT). The execution for the event-based use case was more difficult as there was no strong foundation of an existing design project that could help in framing the analysis and creating a clear scope. In the workflow-based use case, this foundation was present, which made the application of the method more focused.

chapter 6

Second design cycle

6.1 Underpinning the design choices

In the second design cycle the conclusion from the evaluation of the first design cycle, in which the method was tested, will be implemented into the design. Overall, the evaluation in the first design cycle showed the development of the uncertainty analysis method was on the right track. Hence, the second design cycle primarily focusses on further development of the method and detailing. This resulted in the following developments.

Structure of the method: The overall structure of the method and the coherency of the different stages were logical and clear. However, it was highlighted the accessibility of the method and the relevance of the different stages and their goals should be safeguarded. Hence, apart from the structural overview of the method, a process overview was created that specified the goals and output of each of the stages (see Figure 6.1.B). Moreover, the structural overview was further detailed and given the name 'Body Check Analysis' (see Figure 6.1.A). Apart from giving the method a clear recognisable identity, this name and analogy aim to embody and explain the purpose, process and different elements of the uncertainty analysis in a way that is relatable for users of the method.

To safeguard the accessibility of the method, the terminology used has been adapted and stage 3 of the method 'defining causes of uncertainty', which was experienced as the most difficult, has been simplified. Instead of assigning values to the different causes of uncertainty and the perspectives, this stage now focusses on a guided critical reflection on the uncertainty identification in stage 2. The terminology used in stage 2 has been changed. Instead of 'types of uncertainty', 'sources of uncertainty' is used. Within the context of the method, this is a more logical term. Moreover, the number of 'sources' is reduced from thirteen to eleven. The sources 'politics' and 'regulations' have been merged, and the source 'company strategy' is integrated into 'organisational'. These sources were considered too indifferent and therefore difficult to understand or distinguish from one another. Moreover, this will reduce the time needed to execute this stage.

Guidebook: To further develop the method and explain the process in more detail, a guidebook was created based on the flipbook presented in the first design cycle. This provides space for a detailed explanation of not only the method itself but also the theories and principles on which the method is based. For example, rubrics are provided that explain the sources of uncertainty, or help in determining the degree of uncertainty (in stage 2). For most users of the method, these theories and principles will be (partly) new. The guidebook is intended to be reviewed by participants before using the method to make them familiar with the method and the theories. During execution of the method, a facilitator can use the guidebook to guide the process and participants can use the guidebook for reference.

Apart from explaining the method and theories, the guidebook provides an example that illustrates how the method can be used. For this example, the fictional company Bliss Bike Manufacturing is chosen that aims to develop a shared cycling proposition. The topic of cycling or shared cycling is chosen as it is very relatable for most people. Moreover, the product aligns well with the products produced at Nedap in terms of complexity. In other words, when developing a shared cycling proposition, software, firmware and hardware elements are required, and it provides the possibility to collaborate with business partners and other stakeholders.

Introducing the design

The design of the method in this design cycle is primarily further developed and detailed compared to the design presented in the first design cycle. The updated structural overview can be found in Figure 6.1.A. Compared to the previous design, the structure of the method is separated from the direct explanation for each of the stages. Instead, this is captured in a guidebook. As discussed in the 'underpinning the design choices', the method has been given a clear and recognisable name 'Body Check Analysis', which will be further addressed in chapter 7.

The process overview can be found in Figure 6.1.B and explains the goals and output for each of the stages (open this fold-out page on the right-bottom). Moreover, it also highlights how the deliverables between each of the stages are connected.

Designing for Uncertainty

Body Check Analysis

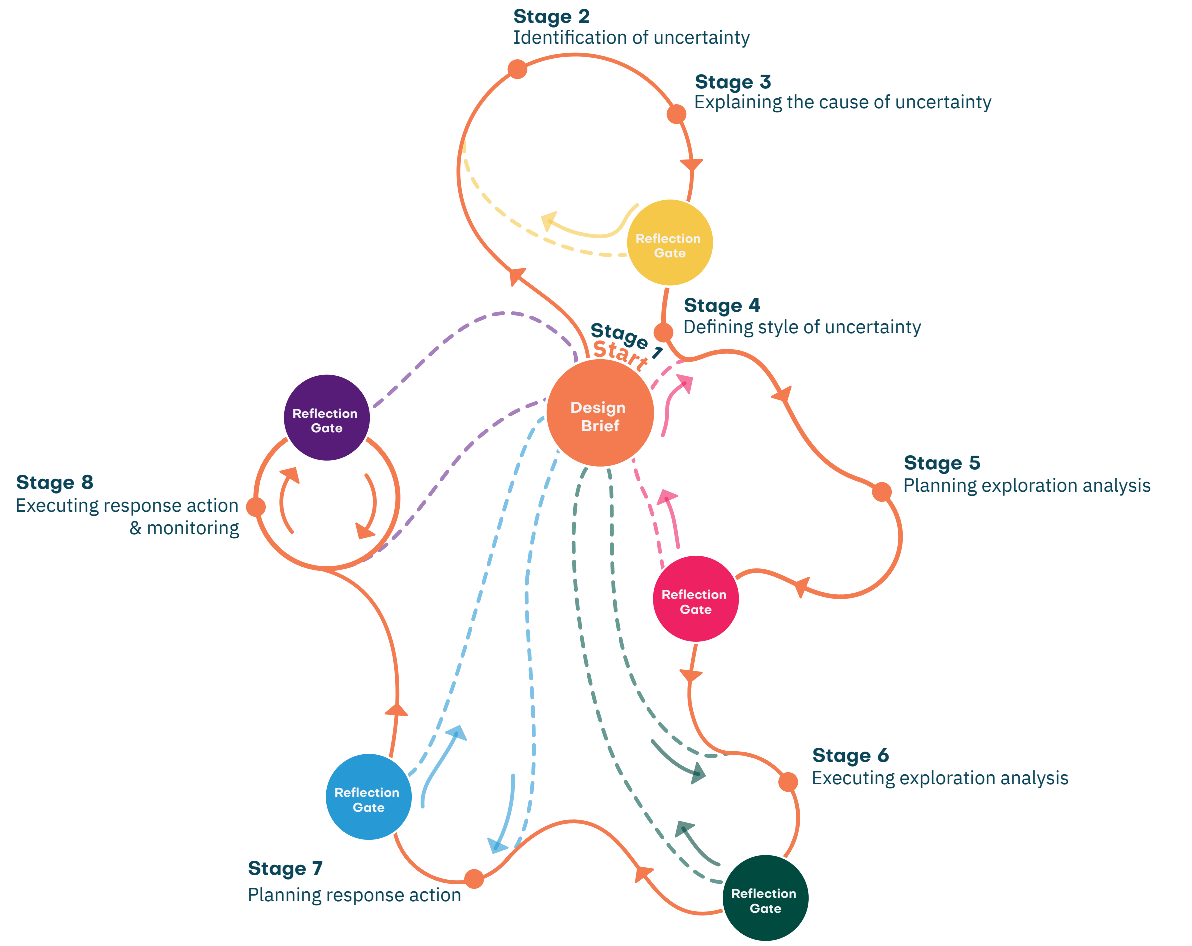

Figure 6.1.A – Structural overview of the Body Check Analysis.

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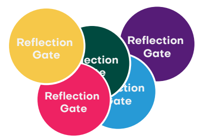
Designing for Uncertainty
Body Check Analysis

This figure describes the overall structure of the Body Check Analysis. For each of the stages, their goal and output will be shown. Every stage logically provides input for the succeeding stage. In case a stage provides *feedback* or *feedforward*, this relationship is indicated with an arrow. View Figure 6.1.A for the structural overview of the method. Here, the overall relationships are indicated.



Goal of the reflection gates
The reflection gates ensure fair and high-quality evaluation during the process. By reflecting amongst others on the purpose of the analysis, more focus is created and irrelevant or unnecessary work can be prevented.

The gatekeeper is responsible for evaluating (together with the group) whether reflection gates can be passed or not, and can decide whether parts of the analysis need to be redone or complemented.

Kutsch, E. & Hall, M. (2009). The Rational Choice of Not Applying Project Risk Management in Information Technology Projects.

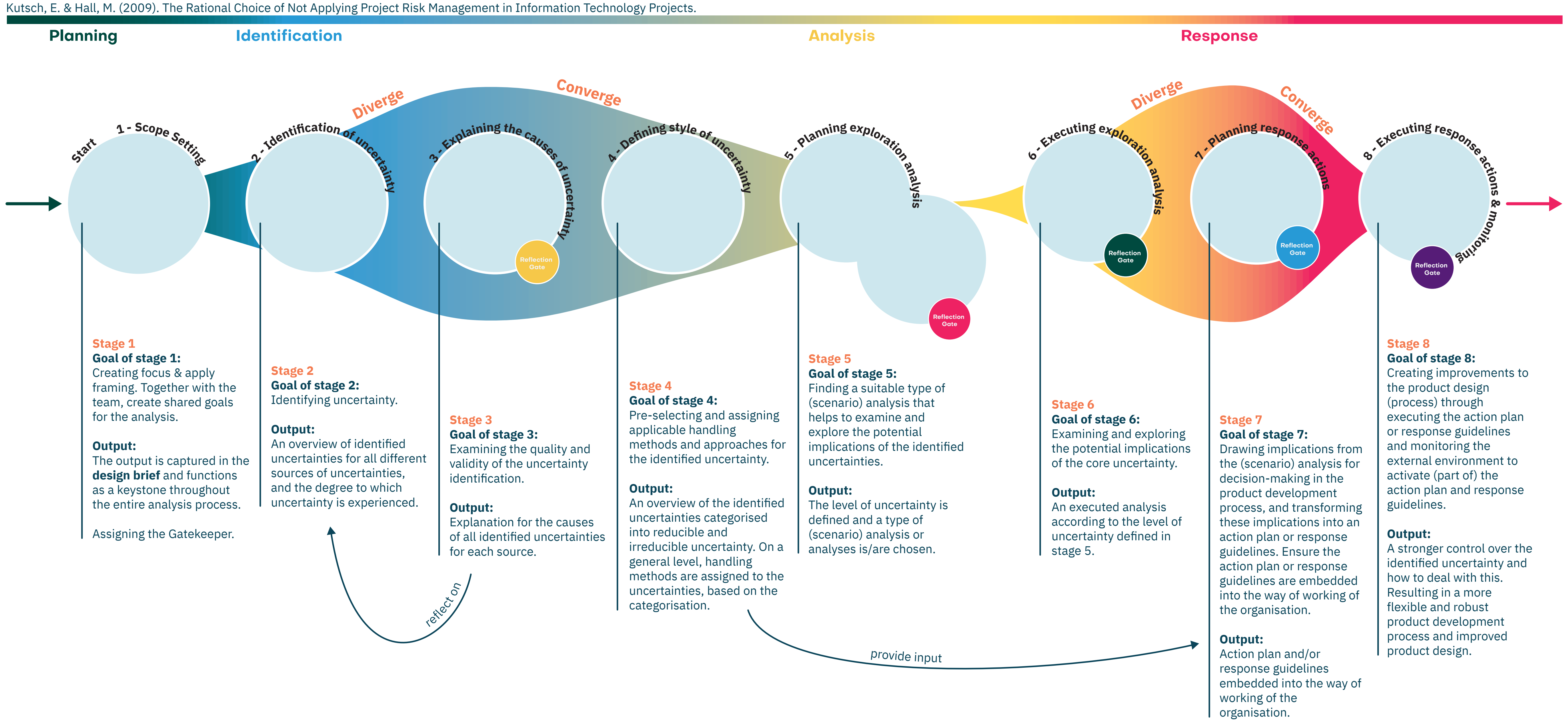


Figure 6.1.B – Process overview of the Body Check Analysis.

In addition to these overviews, a guidebook (see Figure 6.1.C) was created that explains the method in detail and provides examples of how to apply the method. This guidebook is structured in the following three chapters:

- *Why should uncertainty be considered in product development?* This chapter addresses the main principles upon which the method is based and those that are relevant for users to know when applying the method. Amongst others, it explains what uncertainty is and the impact it has on product development.
- *How should the Body Check Analysis be used?* In this chapter, the Body Check Analysis itself is presented. This includes a description of the purpose and goal of the method, what people to include in the process of executing the method, and when to apply the method, to name a few.
- *In what way can the Body Check Analysis be executed?* The final chapter presents a combination of a detailed explanation of how to execute the method and an example case for the fictional company Bliss Bike Manufacturing.

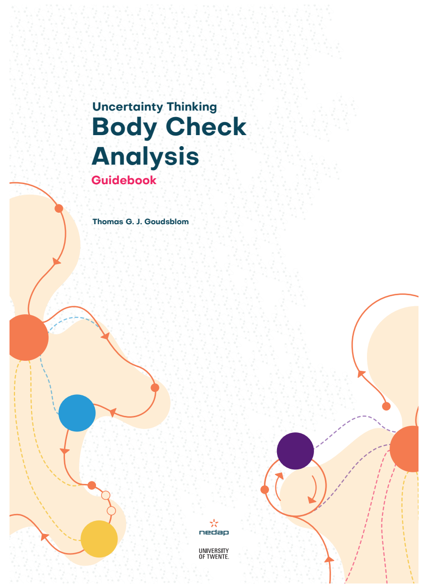


Figure 6.1.C – Illustration of the front page of the guidebook.

6.2 Evaluating the design Case study

The goal of the evaluation is to test the developed method, the Body Check Analysis. Apart from evaluating the functionality of the method, also the added value of the method for product development at Nedap is investigated. The last-named relates mostly to the 'knowledge generation' requirements as discussed in chapter 3. This evaluation is executed in the form of a case study, where the method is applied in four workshops with a group of participants to one of the innovation projects at Nedap. The exact details of this project are confidential. As already introduced in the first design cycle, the project is distinctive due to a high degree of uncertainty, as a technology that is new for Nedap and users of Nedap products is developed for one of their existing markets. The product is developed by the Exploration Team (i.e. innovation team) in collaboration with an external knowledge partner. At the time of this evaluation, the project is at the start of the 'create' phase in the fuzzy front-end of the product development process. When executing the evaluation in the first design cycle, the project was at the end of the 'exploration phase' in the fuzzy front end of product development. This project is chosen for the case study as its development phase fits well with one of the defined use cases for the method (i.e. workflow-based use case), as discussed in chapter 3. Moreover, the characteristics of this innovation project are distinctive for new product development (i.e. evolutionary innovation, see Figure 2.1.C in chapter 2.1) and are expected to provide a good representation for the application of the Body Check Analysis.

The format of a case study to evaluate the design is chosen as it closely reflects the intended use situation of the method (e.g. groupwork, workshops). This will ensure the outcome of the evaluation more accurately reflects an actual use situation. Moreover, applying the Body Check Analysis to an innovation project allows to evaluate the 'knowledge generation' component of the method, apart from only the functionality. This will give insight into the added value the application of the method can offer to the development of the product. The evaluation will be used as input for the final design cycle of this thesis.

Method

The method will discuss the overall structure and set-up of the case study and describe how the case study will be evaluated. To collect data, three different forms of data collection were used: a journal that participants kept track of during the workshops, a questionnaire that participants filled in at the end of each workshop, and an observation.

Set-up of the case study

The case study is executed in four workshops. This format allowed a combination of group work and discussion that reflects the intended use situation of the method. Every workshop was guided by a facilitator (i.e. the researcher), who was also in charge of the introduction of the workshop. The entire method was divided into four logical segments that could be finished within one workshop of 2,5 to 3 hours (see Table 6.2.A). In every session, the created work was used as input for the succeeding workshop.

Table 6.2.A - Overview of the workshops.

This table presents an overview of the four workshops executed as part of the case study. For each workshop, the general composition of participants, the specific stages of the Body Check Analysis to be worked on, the outcome of the workshop, and additional preparations for the participants are shown. Stage 8 of the Body Check Analysis is the execution stage, where the planned response action and the developed early warning system are to be executed. Logically, this could not be done within the time-frame of the case study. Hence, it is only discussed within the boundaries of the workshop.

	Workshop 1 (W1) 4th of July 2023 09.30-12.00	**Workshop 2** (W2) 10th of July 2023 09.00-12.00	**Workshop 3** (W3) 13th of July 2023 09.00-12.00	**Workshop 4** (W4) 20th of July 2023 09.00-12.00
Who	Core team, one person from the extended team	Extended team	Extended team	Extended team
Topic	Stage 1	Stage 2+3	Stage 4+5+6	Stage 7(+8)
Outcome	Design brief	Overview of the identified uncertainties	Uncertainties are evaluated for relevance and impact, resulting in 5 core uncertainties	Early warning system embedded into the way of working
Preparations by participants	-Read guidebook -Think about the main question and purpose for the analysis	-Read the design brief -Think about what uncertainties I experience in my work -Think about what uncertainties we could experience within the development of the proposition		
Templates used	Ecosystem/stakeholder analysis	Wheel of uncertainty	- Mapping reducible uncertainties and assigning handling methods - Uncertainty/impact coordinate system	

In total eight participants took part in the case study (see Table 6.2.B). As they were all Dutch- and English-speaking, the workshops were hosted in Dutch. The materials provided were in English. The participants were grouped into a 'core team' and an 'extended team'. The daily work of participants in the core team primarily focusses on the topic selected for the case study – Innovation project at Nedap – and is in charge of the development of this proposition. The participants in the extended team do not work on this topic. Hence, they were able to bring in new expertise and experiences. As can be seen in Table 6.2.A & 6.2.B, in the first workshop only the core team was invited. However, only two participants were able to attend this workshop. Hence, one member of the extended team was asked to join to allow for more group discussion. For the other workshops, the presence of the participants varied slightly, which was subject to the availability of the invited participants.

Structure of the workshops

Each of the workshops was executed following a similar structure:

Introduction: The workshop stated with an introduction, explaining the purpose of the case study and the goal of today's session, followed by a recap of the previous workshop, and explaining the parts of the Body Check Analysis to be executed during this session. For the first and second workshops, a general introduction to the method the Body Check Analysis and uncertainty in product development was included to ensure all participants were properly informed about the method and the theory. At these workshops also the different forms of data collection were introduced among which the purpose of the journals, as these were already used by the participants during the workshop.

Body: During the main part of the workshop the participants executed the Body Check Analysis. For this part of the workshop, templates were provided that helped the participants execute the BCA (see Table 6.2.A).

Closing: At the end of each workshop, all participants present filled in a questionnaire asking about their experiences of the workshop and their level of understanding of the method.

Table 6.2.B – Overview of the participants of the case study.

This table shows an overview of all the participants part of the case study. For each participant, their role within Nedap, and their presence at the workshops are indicated. The members of the core team are responsible for the development of the proposition - Innovation project at Nedap. The members of the extended team do not work on the mentioned proposition.

			Present at the workshop?			
	Participant	**Role within Nedap**	W1	W2	W3	W4
Core team	Participant 1	Market researcher		Yes		Yes
	Participant 2	Software Engineer	Yes	Yes		
	Participant 3	Innovation Manager	Yes	Yes	Yes	Yes
Extended team	Participant 4	Software Developer	Yes			
	Participant 5	Privacy & Security Officer		Yes	Yes	Yes
	Participant 6	Agile Portfolio Management Consultant			Yes	
	Participant 7	Market Solution Manager; Product Management; Strategy		Yes	Yes	Partly
	Participant 8	Product Owner		Yes	Yes	Yes

Before the workshops
Before the launch of the case study, all participants received a hard copy of the 'Body Check Analysis Guidebook'. This document describes the 'why', 'how' and 'what' of the Body Check Analysis. They were asked to read this guidebook to make themselves more familiar with the method and the theories used. Next to this, before each of the workshops, the participants would receive an email that explained the goal of the upcoming workshop and for some workshops requested additional preparations from the participants. These preparations could vary from reading a section in the guidebook to thinking about certain questions related to the goal of the upcoming workshop.

Forms of data collection
The case study is evaluated through different means; journals, questionnaires and observation. Together, these different forms of data collection aim to capture the experiences of the participants when working with the method as good as possible to evaluate the functionality of the method. As this evaluation is much more elaborate and in-depth than the evaluation in the first design cycle and is expected to deliver more in-depth data and knowledge about the functionality of the method, more thorough forms of data collection are applied. Moreover, the evaluation should provide input for the final design cycle of this thesis.

These three different forms of data collection aim to capture the experiences of the participants both from an internal (i.e. from within a person themselves or the 'self') and external perspective. The internal perspective relates to introspection and retrospection where the participants focus on their own actions, thoughts or emotional state of mind. This form of data collection will give insight into how the participants themselves experienced working with the method. The external perspective relates to observation by watching the behaviour and activities of the participants. This form of data collection will give insight into how the participants behave themselves and interact with each other, and interact with the Body Check Analysis.

Journal: During each workshop, the participants wrote down their thoughts and experiences they encountered when working with the method in a journal. This data collection method is a form of introspection, where the participants focus on their own actions, thoughts or emotional state of mind as they occur. The journal structured this process by providing two categories of statements and/ or questions, and a section that allows for other notes (see Appendix A.5);

- *Insights I have gained during this session!* (e.g. hey, this is something new I learned; this aspect of the Body Check Analysis makes sense; this knowledge is important to remember for my own work).
- *Doubts and difficulties I experienced during this session?* (e.g. this part of the Body Check Analysis is unclear to me; for me, this task was difficult to work on; for this activity, I am doubting whether I am doing the right thing).

Questionnaire: After each workshop, the participants filled in a questionnaire asking about their experiences of the workshop and their level of understanding of the method. This data collection method is a form of retrospection, where the participants focus on their own actions, thoughts or emotional state of mind in the past. This time the reflection was executed after the workshop and allowed for more time to reflect on in-depth questions and the process of the workshop as a whole. After the last workshop (workshop 4), the participants filled in a longer questionnaire that did not only consider the current workshop but also reflected on the entire process and the Body Check Analysis as a whole (see Appendix A.5 for the asked questions). For the closed questions in all questionnaires, a 5-point Likert scale was used. This allowed for sufficiently precise and detailed information.

Observation: During the case study the behaviour of the participants themselves and interaction with each other, and their interaction with the Body Check Analysis were observed. For the first, third and fourth workshops, the observation was executed by the facilitator. At the second workshop, an external observer was present who executed the observation. As the second workshop was the first session with the extended team, this allowed the facilitator to focus more on the group dynamics itself. All observations were overt (i.e. the participants knew they were being observed) and direct (i.e. watching the behaviour, interactions and events as they occurred during the workshop). An observation form was used to take structured notes (see Appendix A.5). Next to direct, indirect observation (i.e. watching the results of behaviour, interactions and events after the workshop) such as the created materials and delivered work was applied. Moreover, video and audio recordings were made to support the observation. This recording allowed the researcher to re-experience parts of the workshop for clarification when the observation form itself was not clear.

Evaluating the data
As there are multiple sources of data input, the relationship between each of the sources and their importance will be discussed. For each workshop, first, a summary of the findings of the journal, questionnaire and observation is shown. And secondly, the final questionnaire is discussed. In the section thereafter, the conclusion of the case study is presented.

When summarizing the findings of the workshops, first the questionnaire is reviewed and complemented with findings from the journal, and secondly, the findings of the observation are added. Both the questionnaire and journal showcase the experience of the participants from an internal perspective through self-reflection. Therefore they are grouped. In this combination, the questionnaire is weighed heavier, as the journal mostly presents snapshots of events, thoughts or experiences, rather than an in-depth reflection on the entire process. The observation captures the experiences from an external perspective and hence forms its own group. When summarizing the findings of each workshop, both these groups are considered equally important.

After completion of the final workshop, participants filled in the final questionnaire, that covers the entire process of the BCA. To be eligible to fill in this questionnaire, the participants needed to be present at a majority of the workshops, of which at least workshops 2 and 4. These workshops are most important in understanding the goals and relevance of the BCA. When concluding the case study, both the summaries of the individual workshops are used, as well as the findings of the final questionnaire. The results of the final questionnaire are weighed heavier, as these findings cover the entire process of the BCA, whereas the summaries of the individual workshops only cover individual parts of the BCA.

The outcome of the workshops

In this section, the outcome of the workshops will be presented. First, for each workshop a summary is given that is structured into two sections: 1) the scope that illustrates an outline of the workshop itself, and 2) the summary of the findings of the questionnaire, journal and observation. The findings are colour-coded:

- Blue indicates a positive evaluation concerning the functioning and added value of the method.
- Orange indicates there is room for improvement in the design of the method.

After the last workshop (workshop 4), the final questionnaire will be discussed. In the section thereafter, the conclusion of the case study will be presented. The conclusion is used as input for the final design cycle.

Workshop 1

Scope: In the first workshop, the core team worked on the first stage of the Body Check Analysis (BCA). Here, they developed the design brief for the analysis that describes the goals of the analysis, main- and sub-questions, relevant stakeholders, and the applied scope.

Findings: Overall, the workshop was experienced as positive, interesting and well-prepared. The topic of uncertainty is very relevant to consider for the development of a proposition. As uncertainty is a big factor in the chances of success of the proposition and dealing with this ahead of time is very important. In addition, the participants shared that reflection on the context of the proposition during product development was viewed as good. During the workshops, some participants shared they had some difficulties understanding the goals of the steps they were doing and how these different steps were connected. For example, performing the ecosystem (stakeholder) analysis (e.g. to what order do certain stakeholders belong?) and defining the risk tolerance (e.g. how to quantify the risk tolerance ?). Next to this, it was questioned whether the steps are project or company dependant. If company-dependent, the implementation of these steps could potentially be the same every time the BCA is executed (e.g. the risk tolerance, and core competencies). When formulating the main and sub-questions of the analysis, it was recognised the sub-questions have been formulated more independently and generally do not have a clear connection to the main question. Moreover, it was also challenging to make the formulated goals specific to the project. Overall, the importance of having a good design brief with clear goals, questions and corresponding scope was highlighted. Moreover, the benefit of executing the BCA was recognised.

Workshop 2

Scope: In the second workshop, the core team together with the extended team worked on stage 2, stage 3 and the Yellow Reflection Gate of the Body Check Analysis (BCA). Here, they executed the uncertainty identification (stage 2), explained the causes of the identified uncertainties (stage 3), and reflected on whether their identification of uncertainty was fair and complete (Yellow Reflection Gate).

Findings: Overall, the workshop was experienced as interesting, and participants indicated it is good to reflect on the development of the proposition and involve people from outside of the project as this helps to prevent some kind of tunnel vision. The discussion between the participants during the workshop was viewed as a valuable aspect of the session. On a generic level, the relevance of the work done in the workshop compared to the overall goal of the BCA and the proposition was high. The structured process of uncertainty identification (stage 2 of the BCA) provides the ability to monitor and respond to uncertainty and prevent difficulties later on in the project, or decrease the impact of uncertainty. Moreover, it can help the project team (of the proposition) to develop their strategy to make well-founded decisions about the future of the proposition and contribute to its possible success. However, it was also mentioned the session was challenging and it was sometimes difficult to execute the different steps. More specifically, the (lack of clarity in) definitions caused confusion (e.g. uncertainty, risk and impact), and explaining the causes of uncertainty in stage 3 of the BCA was difficult. Hence, stage 2 seemed more relevant than stage 3. Also, the order of first stage 2 and then stage 3 seemed illogical. When performing the uncertainty identification in stage 2, participants felt they were no expert on all the sources in the wheel of uncertainty and felt not qualified enough to assess the situation. The guidebook that was provided to the participants was viewed as clear and provided the answers to many questions, however, it was often not consulted.

Workshop 3

Scope: In the third workshop, the core team together with the extended team worked on stage 4, stage 5, Red Reflection Gate, and stage 6 of the Body Check Analysis (BCA). Here, the plan was to identify the style for each of the uncertainties they identified in the previous session and assign applicable handling methods (stage 4). Next, the group would determine the overall level of uncertainty for the entire project and choose a suitable type of (scenario) analysis (stage 5). Followed by reflecting on whether the chosen (scenario) analysis approach matches the goals set in the design brief (Red Reflection Gate).

However, in practice, the workshop followed a slightly different approach. After completing stage 4, they had difficulties executing stages 5 and 6. In stage 5 they choose, with some hesitation, a level 2 uncertainty, that recommends executing a discrete scenario analysis. In the Red Reflection Gate, they determined a scenario analysis would not fit the goals set in the design brief. Instead, in stage 6 only the first few steps of a scenario analysis were executed: 1) The uncertainties identified were all ranked on a coordinate system on 'uncertainty' and 'impact', 2) Finally, the most important uncertainties were grouped into 5 core-uncertainties.

Findings: Overall, the workshop was experienced as challenging, heavier, and more difficult. For the participants it was at some times difficult to identify the relevance of the work they were doing, causing them to feel unproductive. Moreover, the sequence of the different steps seemed illogical. Identifying reducible/irreducible uncertainties (stage 4 of the BCA) was recognised as useful, however, illogical at the prescribed moment as stages 5 and 6 of the BCA do not explicitly follow-up on the created work. During the workshop, there was much discussion on the definition and use of terminology. In some cases, the used terminology caused too much overlap (e.g. degree of uncertainty and level of uncertainty). In other cases, the mere introduction of too many new items caused confusion (e.g. reducible, irreducible uncertainties, and a variety of handling methods, etc.). This created difficulties in determining the level of uncertainty in stage 5 of the BCA. The reflection gate after this stage was viewed by some participants as useful, to check whether the identified level of uncertainty matches the goal of the analysis. Other participants viewed the reflection gate as unnecessary or confusing. At stage 6 of the BCA, the group aimed to execute the scenario analysis matching the level 2 uncertainty (as defined in stage 5 of the BCA). However, they are unable to do this. They found it difficult to understand how to develop scenarios out of the created work, and the relevance the scenarios would have to the entire process. It was mentioned, that a more visual explanation of the process of the BCA could help understand the relevance of the different stages and the work that was done better.

Workshop 4

Scope: In the last workshop, the core team together with the extended team worked on stage 7 and the Blue Reflection Gate of the Body Check Analysis (BCA). Here, they created an early warning system (i.e. plan of action) for the 5 core-uncertainties defined in the previous workshop and embedded this early warning system into their way of working. This early warning system consisted of a monitoring aspect (how can developments in these uncertainties be observed, i.e. trigger events) and a plan of action (how to respond to developments in these uncertainties). Note, as the previous workshop followed a slightly different approach, no scenarios were used as input but the core-uncertainties themselves instead. As after this workshop the eligible participants would fill in the final questionnaire that reflects on the entire process of the method, the workshop started with again presenting the story line and goals of the BCA. This was done to help place the final workshop into perspective of the work that already had been done in previous workshops. To do this, a new figure was created (see Figure 6.2.C) and used in this presentation. Feedback from previous workshops indicated the other overviews were good at explaining the structure of the method, however, not good at explaining the process and storyline of the method.

Findings: Overall, the workshop was experienced as very positive, concrete and hands-on. Participants felt they developed concrete tangible actions that contributed to answering the main question in the design brief. The final stage (stage 7 of the BCA) that was executed in this workshop, combines all the work that has been done in previous workshops and identifies concrete response actions and monitoring that can be executed to contribute to the success of the proposition in obtaining a leading market position. Embedding the early warning system (i.e. the plan of action and monitoring) into the way of working was seen as very valuable. The analysis did not yield shocking new insights but rather provided details and nuances and helped to identify the important actions that need to be done. Assessing the assumptions and uncertainties in a more objective way (compared to their normal way of working) was seen as valuable. Moreover, including people from outside the core team helped to prevent tunnel vision and was believed to help create better product solutions. The group also stated that the blue reflection gate is very strong and relevant. They concluded they had not lost focus of the main question throughout the process of executing the BCA. Simplifying the method to the level participants experienced in this workshop would be very helpful. Participants expect it will take out much of the discussion points during the workshops that concern terminology and definitions used and will improve the execution of the method.

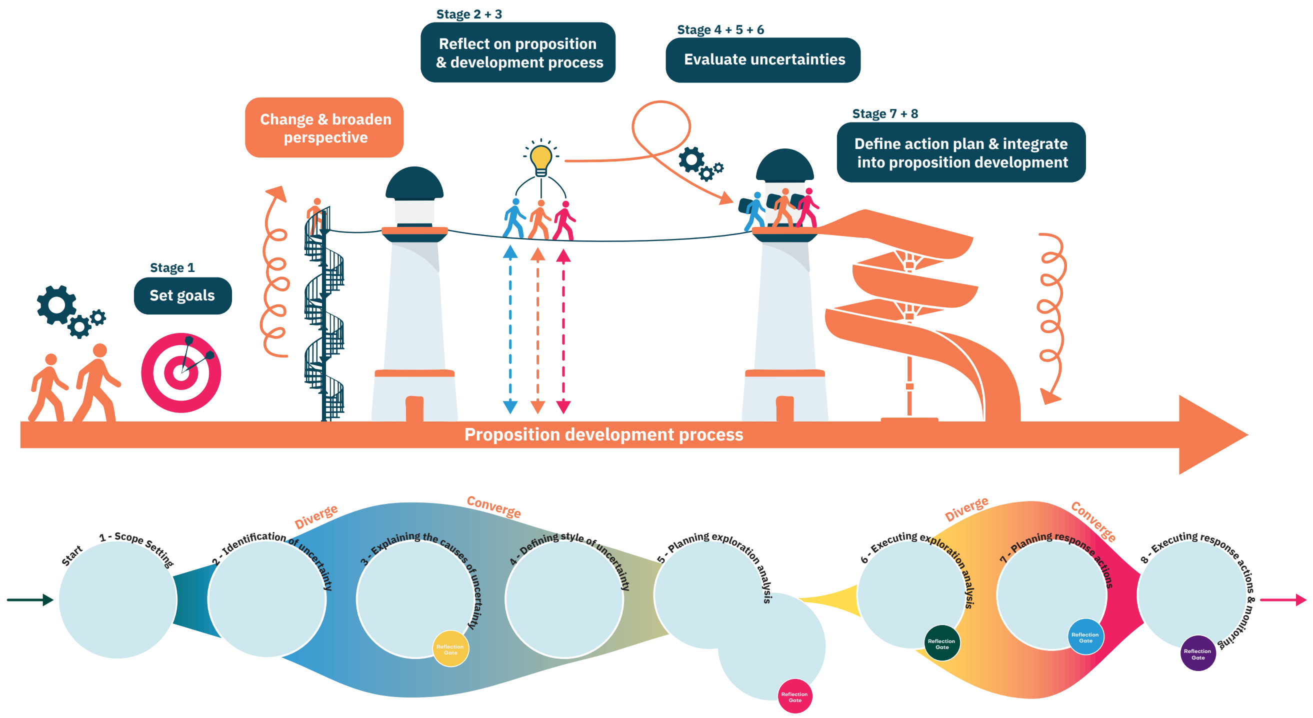


Figure 6.2.C – Visualization of the Body Check Analysis process. Used during the introduction at the 4th workshop to highlight the storyline of the process and the work the participants have done. The story reads:

> "Left, in the first session we formulated the main question with the core team of 'Innovation project at Nedap'. We then climbed a high tower and in the second session we brought in new people with different expertise and insights from outside the team to look at the development process of the proposition together from a new, broader and higher perspective. During this second session we reflected on 'Innovation project at Nedap' by, among other things, identifying a broad spectrum of uncertainties. In the third session we processed the new insights. By evaluating the uncertainties for their impact, we have come to 5 core uncertainties. Today, we have arrived at the slide and we are going to transform these 5 core uncertainties into a plan of action and integrate them back into the proposition development process."

Final questionnaire

The final questionnaire covers the entire process of the Body Check Analysis and was filled in after the end of the fourth workshop. The questionnaire was constructed of both open and closed questions. The closed questions were answered on a 5-point Likert scale that can be found in Figure 6.2.D. The open questions will be discussed below.

Q22: How did working with the BCA influence your view on uncertainty in product development?
Most respondents shared that working with the BCA brought them a broader perspective. It helped them to make uncertainty in the product development process explicit through identification and creating ways to deal with uncertainty or define initial steps to mitigate it. One respondent indicated in product development they should frequently (e.g. quarterly) take a moment to reflect on the uncertainties and define ways to deal with them. One participant shared that their view on uncertainty in product development did not change.

Q23: In what way(s) does the Body Check Analysis provide value to product development at Nedap?
The participants described the added value as a tool (or structured approach with practical examples) that people can use to identify uncertainties and reduce them. Another participant described this tool more as a checklist that helps to, more objectively than is done now, determine uncertainties and support the discussion on how to assess these. It was also shared that the BCA, through uncertainty identification, can help in determining the success of a potential proposition to our portfolio.

Q24: After having worked with the BCA, what have you learned?
It is important and can be valuable to involve people from outside the project or domain as they can provide new insights. In addition, background knowledge of different sources of uncertainties (i.e. market, environmental, competitors, politics, etc.) is necessary to identify uncertainties properly. However, it was also indicated it is not always easy to work with people who have a different level of knowledge about the proposition. It seemed that the results of the analysis were generic and possibly applicable to other projects. One participant shared they learned that they and their colleagues think differently on some of the topics. Many elements of the BCA the participant was already doing in their mind, but not so explicitly. Another respondent learned that the BCA method is rather extensive. It will help participants not to miss insights by forcing them to take different viewpoints, which facilitates good discussion. But it does not naturally lead to a new action plan. Some parts of the method seemed to add little value or have a low relevance.

Q25: When reflecting on the entire process, what parts of the method (e.g. stages, reflection gates) provided the most valuable contribution to the entire process?
Most respondents shared they found that stage 2 'identification of uncertainty' contributed the most value to the entire process. Making people aware of the uncertainties and reviewing the proposition from different perspectives was seen as very important. Followed by determining a response plan & early warning system (stage 7). Also, the discussions during the workshops were highly valued. One responded shared they found mapping the uncertainties for their potential impact and uncertainty in stage 6 was also very relevant. Another participant stated that the reflection gates had the most important contribution. As it is important to reflect on the work that is being done and whether this still contributes to the main goal.

Presence of the respondents at the workshops:

	Workshop 1	Workshop 2	Workshop 3	Workshop 4
Participant 1		Present		Present
Participant 3	Present	Present	Present	Present
Participant 5		Present	Present	Present
Participant 7		Present	Present	Partly
Participant 8		Present	Present	Present

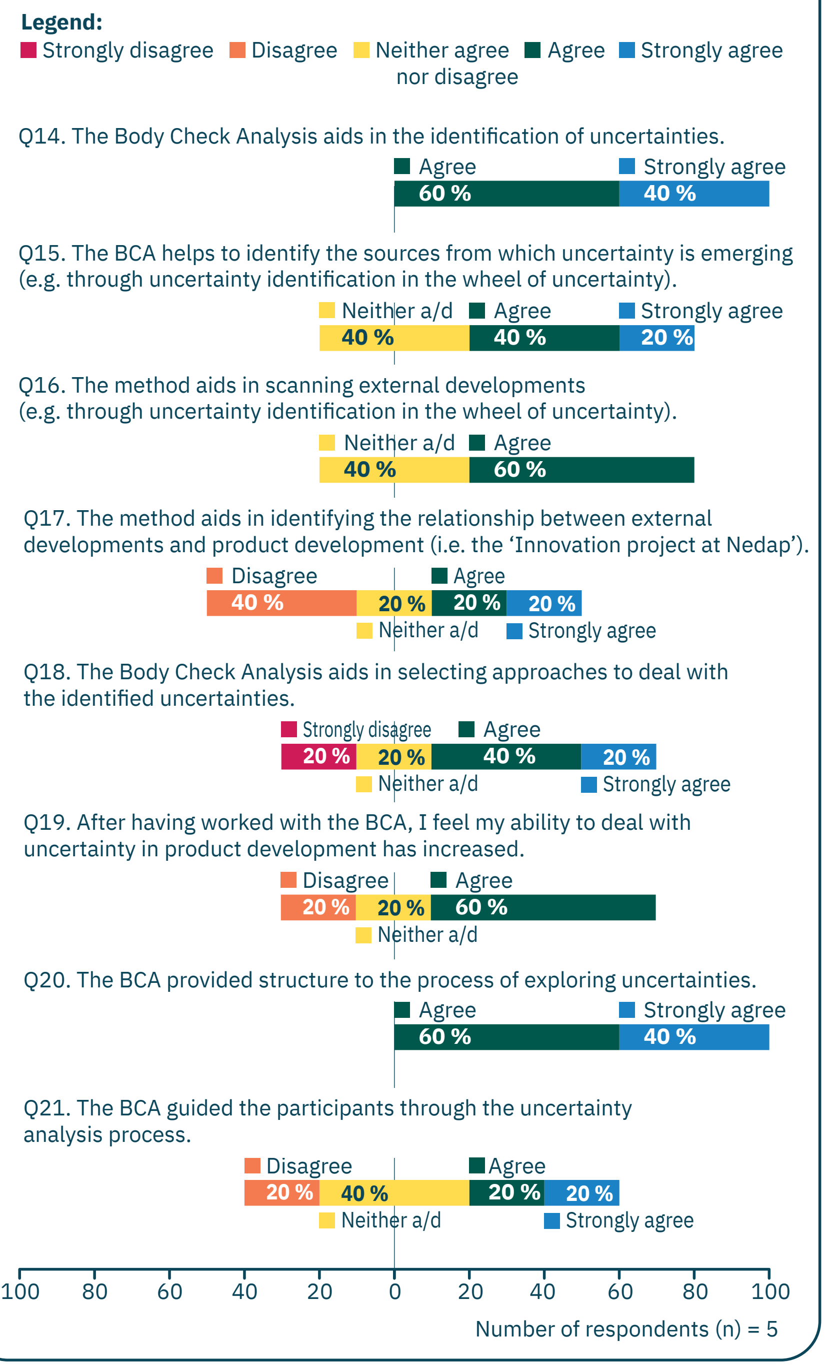


Figure 6.2.D – Responses from the final questionnaire of the case study. On the top, the presence of the participants at the workshops that filled in this questionnaire is shown. The questions were answered on a 5-point Likert scale. The answer options for the questions are shown in the legend on top. The graph presents the total percentage of each provided answer. The third answer option (yellow) out of 5 is fitted in the centre of the axis.

Q26: When looking back on the entire process, what parts of the method (e.g. stages, reflection gates) provided the least valuable contribution to the entire process?
Most respondents shared they found that the 'middle stages' contributed the least value to the entire process. Meaning, stages 4, 5, (and 6). This part seemed to question the work that was done before, felt unnecessary or made the steps before senseless. One respondent shared they found embedding the early warning system (i.e. action plan or response actions) into the way of working the least valuable part of the BCA. Another respondent indicated they were unsure what had happened to the degrees of uncertainty they had assigned in stage 2 to the different sources of uncertainty in the wheel of uncertainty.

Q27: Is there anything else you would like to share? Or do you have any suggestions?
One respondent shared that they felt the effort for completeness caused more confusion and introduced vagueness on the added value or relevance of the BCA. A better balance between completeness and usefulness can be found. Moreover, they also recognised it might be valuable to test the BCA on another project to prevent a project-dependent evaluation of the BCA. Another respondent shared they liked the workshops very much.

Concluding the case study

The goal of the method is to aid the decision-making process in product development at Nedap to cope with uncertainties. In this case study, the Body Check Analysis (i.e. the method) has been executed for the application of the described proposition. With the goal of testing the developed method, use the gathered findings to evaluate the method, and use the evaluation as input for the third design cycle.

Uncertainty is very relevant to consider for the development of a proposition. It is a strong factor in determining the chance of success of the proposition and dealing with this ahead of time is very important. The Body Check Analysis (BCA) aids very well in the identification of uncertainty and examining the source from which the uncertainty is emerging. Working with the BCA helped participants to make uncertainty in product development explicit and create concrete tangible ways to deal with the uncertainty and make well-founded decisions about the future of the proposition. Moreover, most of them agreed that working with the BCA increased their ability to deal with uncertainty in product development. They did this by scanning the external environment for developments (the wheel of uncertainty in stage 2 of the BCA). However, in some cases, it was difficult to identify the relationship between external developments and the proposition. Participants indicated that background knowledge of the different sources of uncertainty (i.e. market, organisation, technology, etc.) is necessary to identify and examine uncertainties properly.

Although the method provides a rather extensive approach to structured uncertainty identification, which helps participants in not missing uncertainties by supporting them to take different viewpoints, and facilitates good discussion. It was also recognised the effort for completeness caused more confusion and introduced vagueness about the added value or relevance of the BCA. For example, stage 3, where the cause of the identified uncertainty is explained was experienced as difficult and added little value to the entire process. And at some moments, participants had difficulty with identifying the relevance of the work they were doing due to an illogical sequence of steps or how the different steps were connected. For example, in stage 4, uncertainties are categorised as reducible or irreducible, and handling methods are assigned to the reducible uncertainties. Only in stage 6, the irreducible uncertainties are treated, where they are amongst others evaluated for their uncertainty and impact. This caused participants to feel confused and unproductive, as in the previous stages they defined ways to deal with the reducible uncertainties without evaluating them for their impact first. Stage 5 identified the level of uncertainty, aiming to select suitable approaches to further examine the uncertainty and define ways to deal with it. The terminology of 'level of uncertainty' clashed with the previously introduced 'degree of uncertainty' in stage 2, and the new theory and logic caused confusion among the participants. Hence, the participants were not able to fully execute stage 6 where the selected approach in stage 5 is executed.

When concluding the case study, it could be recognised stage 2 'uncertainty identification' and stage 7 'planning response actions' formed the most valuable contribution to the entire process of the BCA and the development of the proposition. Stage 1 'scope setting' was seen as essential, as it forms the basis of the analysis and helps to maintain focus on the goals during the execution of the analysis. Stage 8 'executing response actions' fell beyond the scope of the case study, however, it was seen as a very important part of the process. The other stages in their current form added little value to the process of the BCA, and in some cases caused confusion. Overall, the reflection gates formed a valuable part of the process. They helped to reflect on the main question and goal of the analysis to ensure focus throughout the entire process. However, in some cases, the reflection gates felt repetitive or difficult to execute. The diverse group composition helped to reflect from a broader perspective on the development of the proposition, which can help prevent tunnel vision. However, it proved challenging during the process and in discussions some participants had a better understanding of the proposition than others. This caused the participants who had a better understanding to take a more leading role and other participants to feel somewhat unqualified when making decisions related to the proposition.

6.3 Reflection on the requirements

In this section, an intermediate reflection on the requirements is presented. Based on the findings and conclusion of the case study, this reflection will determine which design improvements are required for the third design cycle. These improvements will be presented in the 'underpinning the design choices' section of the next chapter.

When reflecting on the main goal of the method as formulated in the stated purpose, it can be recognised the BCA can partly fulfil this goal (also see Table 6.3.A). The BCA enables the identification of uncertainties and to a certain extend aids in the selection of suitable approaches to deal with the uncertainty. During the case study, participants were not able to explore future challenges and examine the potential relationship between these challenges and product development, however, they were able to examine the external environment at present-day for challenges and identify accompanying opportunities and risks. The method shows potential to aid the decision-making process to cope with uncertainties, however, during the case study it became clear the current structure of the method does not yet fit Nedap as the process was too complex. As this is an essential part of the goal, a third design cycle is required to address this objective. In Table 6.3.A, a reflection on each of the requirements is presented.

Table 6.3.A – Intermediate reflection on the functional requirements.

	The method should...	
1	**Knowledge generation**	Reflection
A	...aid identification of uncertainties	Yes, The BCA aids very well in the identification of uncertainty and examining the source from which the uncertainty is emerging.
B	...support scanning of external developments and identify their relation to the product development	Partly, the BCA aids in scanning the external environment for developments through the use of the wheel of uncertainty in stage 2 of the BCS, however, in some cases, it was difficult to identify the relationship between external developments and the proposition.
C	...aid in examining the potential impact of uncertainties on product development	Yes, the BCA aids in evaluating the impact of uncertainties on the product development process.
D	...aid in exploring future challenges and identifying accompanying opportunities and risks	No, participants were not able to execute the part of the method that most strongly connects to this requirement (scenario analysis in stage 6), due to amongst others the structure of the method.
E	...aid in selecting approaches to cope with the identified uncertainty	Inconclusive, the responses varied greatly. A majority indicated the BCA did help them select approaches to cope with the identified uncertainty, however, a small minority (strongly) disagreed with this.
F	...help in identifying crucial decisions	No, the BCA does not specifically help in identifying crucial decisions. However, it does help in identifying the most important uncertainties and the decisions that need to be made to cope with those.
2	**Usability**	
A	...increase the ability of designers to control uncertainty	Yes, most participants agreed that working with the BCA increased their ability to control uncertainty in product development.
B	...be suited to the product development process of Nedap	No, the BCA shows potential value to the product development process at Nedap, however, participants indicated the current structure of the method is not yet fully functional for the current use context.
C	...be clear how and when to use the method in the product development process	Partly, participants indicated the relevance of applying the BCA in this stage of the product development process was clear to them, however, the structure of the method that explains how the method should be executed was not yet fully clear.
D	...provide structure to the process of exploring uncertainties	Yes, participants were conclusive that the BCA provided structure to the process of exploring uncertainties.
E	...guide the users through the uncertainty analysis process	Inconclusive, the responses varied greatly.
F	...be suited to the decision-making process of Nedap	Yes, by embedding the action plan into the way of working at Nedap in stage 7 of the method, any decisions that need to be made as an outcome of the BCA are aligned with the decision-making process at Nedap.

chapter 7
Third design cycle
Final design

This chapter presents the final design. First, the most important decisions made that have led to changes to the design are presented. Thereafter, the final design itself is discussed, and the chapter is closed with an evaluation of the design and an assessment of the requirements.

7.1 Underpinning the design choices

In the third design cycle the conclusion from the case study of the second design cycle, in which the method was tested, will be implemented into the design. Based on these learnings, the following design choices are made.

Simplification of the method: The introduction of many new theories and definitions, in combination with the new logic the method provides, caused confusion and made executing the method more difficult. Hence, some degree of simplification is required. The number of stages has been reduced. Resulting in fewer but more clearly distinguishable stages that focus on the core aspects of the method. Complex language and ambiguous definitions are eliminated where possible to avoid confusion or have been explained more extensively. This resulted in the following main changes:

- Stage 3 'Explaining the causes of uncertainty' is removed. This stage was experienced as very difficult and added little value to the overall process in its current form. The goal of this stage 'to examine the quality and validity of the uncertainty identification' is now partly embedded in the blue reflection gate of stage 2 in the new design (where the uncertainty identification is executed), as this goal was seen as relevant to the process.
- After the uncertainties have been identified, all uncertainties are evaluated for their relative uncertainty and impact. This helps to define the core uncertainties (i.e. the most important uncertainties to deal with).
- Stage 4 'Defining the style of uncertainty' is only applied to the core uncertainties. This reduces the workload greatly when executing the method and creates a more logical structure.
- Stage 5 'Planning exploration analysis' and stage 6 'Executing exploration analysis' are removed. They added confusion to the process of the analysis and were difficult to execute. The scenario-based approaches in these stages could add value when the identified uncertainty is very complex or multifaceted and needs further investigation before an action plan can be created. However, they are not a necessity for the uncertainty analysis. Subsequently, the 'degree of uncertainty' in stage 2 has been taken out as this approach to measure the degree to which uncertainty is experienced was only relevant for the execution of stage 5.

It is expected this simplification will somewhat negatively impact the completeness of the method (i.e. its ability to achieve the goals of the method), however, it is also expected it will greatly improve the usability and applicability of the method.

The goal of the method and connection between stages: Although the overall goal of the method is clear, the relevance of each of the different stages and the connection between those are not always understood. Hence, a clearer and more visual explanation is made to strengthen the interpretation of the method and the relevance of the different stages.

Knowledge requirements and preparation for participants: To utilize the input of the different participants more and create more valuable outcomes of the analysis process, the following preparations should be made by the participants. All participants need to have some level of understanding of the topic of the application (e.g. the design/product development project). This can be achieved through for example a presentation by the development team before the execution of the method to all participants. Next to this, the group of participants needs to have some knowledge of the different 'sources of uncertainty'. This can be achieved through for example bringing in experts from the different domains (e.g. politics, technology, natural environment, etc.) and/or all participants researching one or more sources before the execution of the method as preparation.

Introducing the final design

The designed method – the Body Check Analysis or BCA – helps designers and decision-makers gain more control over uncertainty in product development by aiding the decision-making process to cope with uncertainty. It provides a structured method to identify uncertainties in the product development process, explore their potential impact, and define ways to deal with them. The BCA is a stage-gate uncertainty analysis method for product development and innovation. In Figure 7.1.A, a structural overview of the method can be found. This overview explains the structure of the method and how the different stages and gates are connected. Each of the stages focuses on a key activity in the process of uncertainty analysis and specifies concrete activities that should be executed in the analysis process.

The Body Check Analysis represents an amorphous human figure that aims to adapt its lifestyle activities more specifically to what it requires or will require in the future to become stronger, healthier and happier (see Figure 7.1.A). This is done by scanning its body and current lifestyle to determine its composition and personal needs. In product development and innovation, the 'body scan' will include a scan of the product design and its product development process. Aiming to decompose the uncertainties and challenges that are inherent to the design process, and find ways to adapt the decision-making process to deal with these uncertainties and challenges, now and in the time to come. The design brief forms the pumping heart of the analysis, and determines the pace, rhythm, and depth in which the activities are executed. The different flows to and from the heart ensure all stages and gates are connected and aligned.

Figure 7.1.A shows the structure of the method and how the different stages and gates are connected. This figure is especially useful when working with the reflection gates. It shows what parts of the method need to be included when performing this reflection and what parts of the method need to be reconsidered when a gate cannot be passed. In Figure 7.1.B (open this fold-out page on the right-bottom), the process of the method is addressed in a storytelling approach. This overview helps to understand how the method is executed and what happens in each of the stages. This figure is most useful when explaining the method and highlighting the relevance of each of the stages towards the product development process. The different stages and reflection gates are addressed in Figure 7.1.B.

In addition to these overviews, a guidebook explains each of these stages in detail, provides an example about the fictional company Bliss Bike Manufacturing on how to apply the method, and can be used as a guide when executing the uncertainty analysis. To support the execution of the method, templates are available for stages 1 to 4. Both the guidebook and the templates can be found in a separate Appendix.

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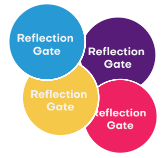
Uncertainty Thinking
Body Check Analysis

This figure describes the overall structure of the Body Check Analysis. For each of the stages, their goal and outcome will be shown. Every stage logically provides input for the succeeding stage.

View Figure 7.1.A for the structural overview of the method. Here, the overall relationships are indicated.



The goal of the reflection gates
The reflection gates ensure fair and high-quality evaluation during the process. By reflecting amongst others on the purpose of the analysis, more focus is created and irrelevant or unnecessary work can be prevented.

The gatekeeper is responsible for evaluating (together with the group) whether reflection gates can be passed or not, and can decide whether parts of the analysis need to be redone or complemented.

Kutsch, E. & Hall, M. (2009). The Rational Choice of Not Applying Project Risk Management in Information Technology Projects.

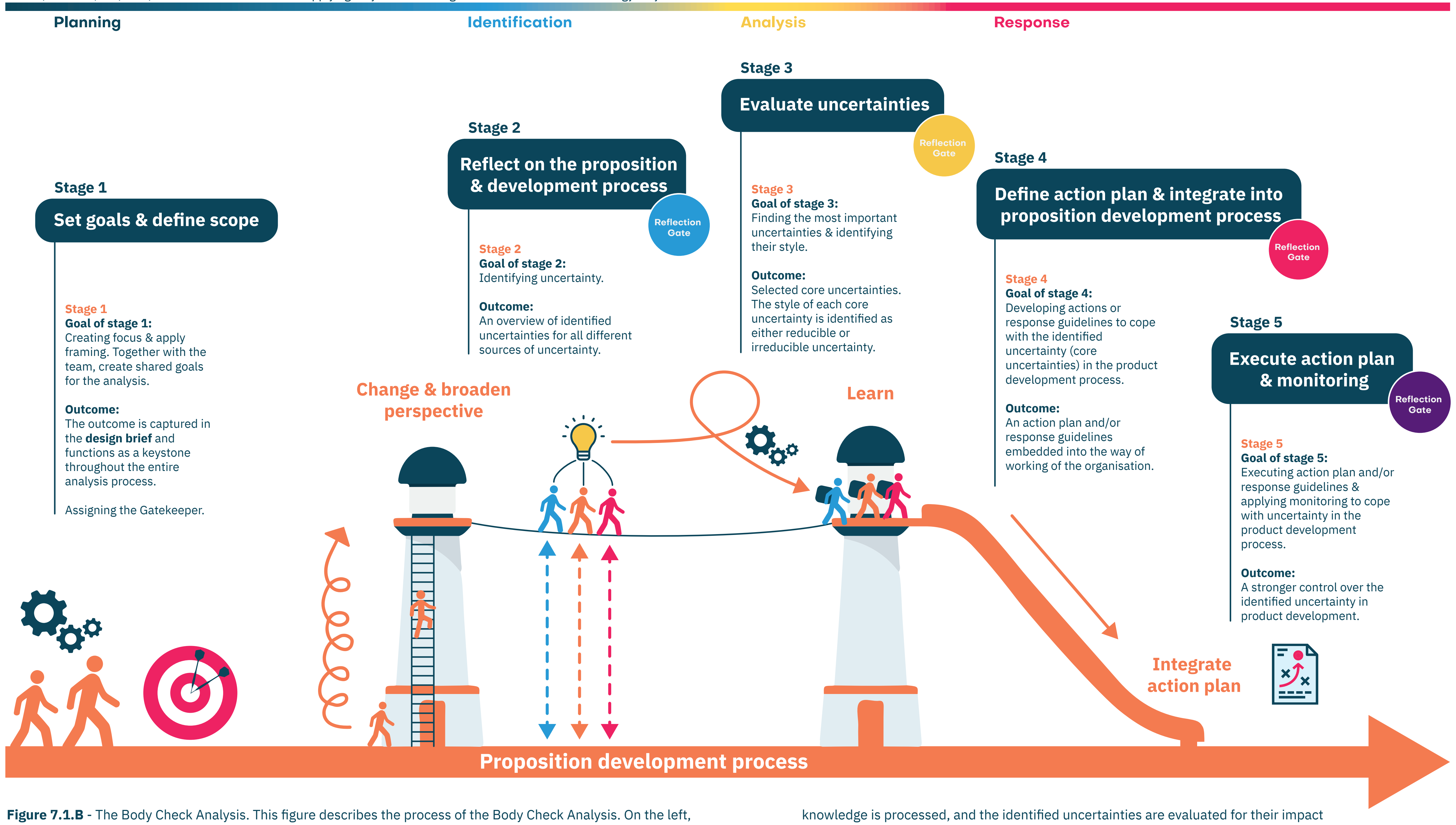


Figure 7.1.B - The Body Check Analysis. This figure describes the process of the Body Check Analysis. On the left, in stage 1, the goals for the analysis are formulated and captured in the design brief. Then, in stage 2, a high tower is climbed to reflect on the proposition development process with a diverse team with different expertise and insights from a new, broader and higher perspective. A spectrum of uncertainties is identified. In stage 3, the new knowledge is processed, and the identified uncertainties are evaluated for their impact and uncertainty to identify the most important - core - uncertainties. On the right side, in stage 4, the core uncertainties are transformed into an action plan and integrated into the proposition development process. In stage 5, the action plan is executed and monitored.

Uncertainty Thinking
Body Check Analysis

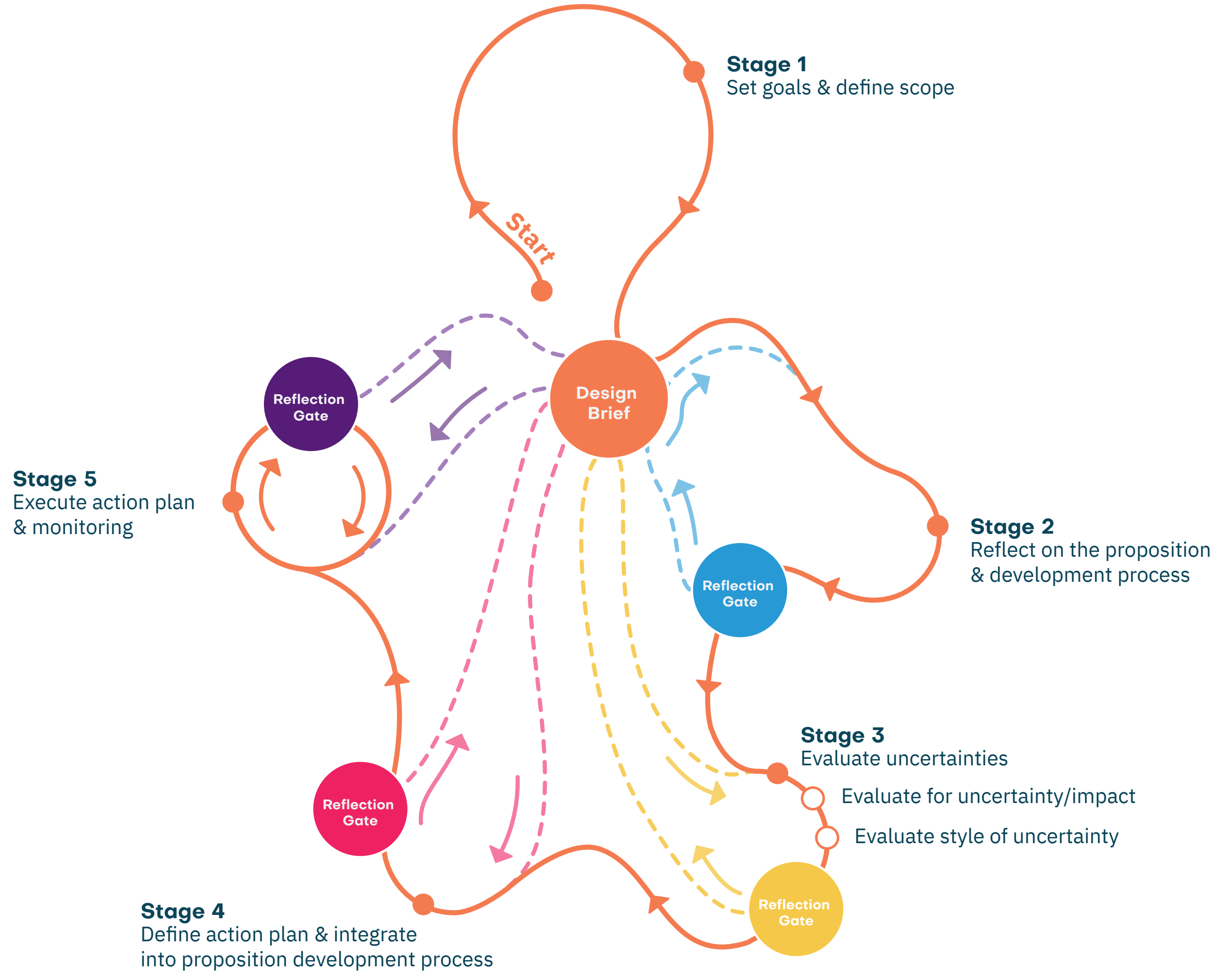


Figure 7.1.A – Structural overview of the Body Check Analysis.

How to use the method?
The BCA is intended to be executed in a group workshop setting with the guidance of a designated facilitator who manages the process and supports group dynamics. This way, the group can fully focus on the analysis itself. In each workshop, one or more stages are completed. These workshops must be planned consecutively (i.e. no more than a few days or a week between two sessions). Otherwise, it might be more difficult for the group to recollect the work they had done in earlier workshops and this can hinder the overall process. The group should include participants from diverse backgrounds and expertise, apart from the members of the product development team itself. Inspired by the 'remarkable people' as discussed in the research of Bradfield et al. (2005), bringing in people with new knowledge will stimulate and challenge the thinking of the group. This helps in creating a more comprehensive overview of identified uncertainties and stronger response actions to these uncertainties. For example, when six people are part of the BCA team, two of those are part of the product development team itself of which at least one has a strong technical background, one from marketing, one from sales, one from product management (also gatekeeper), and one from operations.

The value of performing team-based uncertainty analysis transcends the mere deliverables it provides. The mental exercises support team building and create a learning process. It normalizes admitting 'we do not know', and pushes the organisation to become a learning organisation for innovation management (Millett, 2003; Rice et al., 2008). Hence, the importance of the BCA lies not only in the results it generates but also in the process and way of thinking it engages within the organisation.

The role of the gatekeeper
To ensure fair and high-quality evaluation during the process, a gatekeeper needs to be assigned. The gatekeeper is responsible for evaluating (together with the group) whether reflection gates can be passed or not, and can decide whether parts of the analysis need to be redone or complemented. To do this, it is important the gatekeeper can bring an independent perspective into the analysis process. Hence, the gatekeeper cannot be part of the product development team itself and should be able to place the product development process and uncertainty analysis in a broader perspective. For example someone in product management from a different department within the organisation.

The role of the gatekeeper is an addition to the stage-gate approach of the BCA itself. This approach helps to assess the quality of execution of the method and understand whether the uncertainty analysis is on the right track. Moreover, it helps to maintain focus throughout the process by continuously reflecting on the objectives set in the design brief. The gatekeeper should safeguard this approach.

When to use the method?
For the application of the method, several use cases have been defined that illustrate when the method can be used.

- *Use case 1 - Workflow-based use case*: During the fuzzy front end of product development (i.e. at the end of the 'exploration' stage or the start of the 'create' stage in proposition development at Nedap) the method is used as a reflection tool to support decision-making regarding the focus of the development activities and deliver input. Here, the use case is embedded into the organisational planning and working cycle.
- *Use case 2 - Action-based use case*: Before large investments or decisions are made, the method is used to support decision-making. For example, deciding to take over another company to foster product development, the acquisition of specific technology, or deciding whether a project can be scaled to a new product development phase (i.e. from 'create' to 'scale').
- *Use case 3 - Problem-based use case*: When uncertainty-related difficulties are experienced in the development, or the development team gets stuck, the method is used to analyse the problems and find a solution direction or select development activities. For example, the envisioned product concept or solution seems unfeasible.

7.2 Evaluating the final design User test

The goal of this evaluation is to test the final design of the method for its usability and functionality. The evaluation of the method in the second design cycle already showed the value of working with the Body Check Analysis to cope with uncertainty in product development. However, it was also recognised the method was too complex and the structure was illogical at times, causing the previous version of the method to be difficult to apply and therefore not suited to the development process at Nedap. Hence, this evaluation focuses on investigating the following elements of the re-design:

- Structure and logic of the method.
- Relevance of the different stages and gates to the goal of the method and how well this is communicated to the users.
- Usability of the method.

As these elements strongly focus on the functionality of the method, rather than the knowledge it generates or the added value it could offer to Nedap or product development, they are evaluated in a user test. In this section, first, the method of the user test will be discussed, and second, the conclusion of the user test will be presented.

Method

The method will discuss the overall structure and set-up of the user test and describe how the user tests will be evaluated. To collect data, three different forms of data collection were used: a journal that participants kept track of during the evaluation session, a questionnaire that participants filled in at the end of the session, and an observation.

Set-up of the evaluation
In the user test, which was conducted in one session of 3 hours, two participants jointly executed the method with again the 'Innovation project at Nedap' as the applied product development project (see Table 7.2.A). Both of these participants were also part of the case study in the second design cycle and hence were somewhat familiar with the used principles in the method. As the method design itself is different (in terms of structure), this prior experience in working with some of the applied principles was not identified as a problem for the user test. However, it might influence their behaviour when working with the method. The user test enables evaluation of the method with a strong focus on the direct human-product interaction, which is important when investigating the above-mentioned focus elements of this evaluation. Compared to the case study in the second design cycle, it is assumed the group dynamics have a smaller influence on the evaluation due to a reduced group size (from around five in the case study to two in the user test). Moreover, during the user test, less focus is required for the project-specific content discussion as the project itself had already been discussed in the previous case study. The participants focused on examining the logic and structure of the method by exploring the different stages and gates for the application of the 'Innovation project at Nedap'. When doing this, they executed all stages and reflection gates, however, not all stages were executed in full detail.

Table 7.2.A – Overview of the different participants in the user test.

Participant	Role within Nedap	Applied product development project
Participant 1	Innovation Manager	Innovation project at Nedap
Participant 2	Market researcher	Innovation project at Nedap

Structure of the evaluation
During the user test, the following structure was followed:
Introduction: The session started with an introduction, where the purpose of the user test and the goal of today's session were explained. Thereafter, the re-designed method was introduced and the different stages and reflection gates of the method were presented.
Body: During the main part of the session, the two participants executed the Body Check Analysis. A copy of the guidebook and printed templates for stages 1, 2, 3 and 4 were provided.
Closing: At the end of the session, the two participants filled in a questionnaire asking about their experiences during the user test. Thereafter, the user test was closed by briefly discussing their experience of the session.

Data collection
The user test is evaluated through a journal the participants kept track of during the session, questionnaire and observation. Together, these different forms of data collection aim to capture the experiences of the participants when working with the method as good as possible to evaluate the usability and functionality of the method. Each of these forms of data collection is applied in a similar way as discussed in the second design cycle. Unfortunately, due to equipment malfunction, it was not possible to record the session. Hence, the observation is based on the notes taken by the researcher during the user test. View chapter 6.2 to read more about each of these forms of data collection and how the findings from each of these forms of data collection are evaluated.

The outcome of the user test

In this section, the findings are discussed. First, the observations will be presented, after which the questionnaire is discussed. As the journal did not provide findings that were not already provided in the observation or questionnaire, it is not discussed separately.

After the introduction presentation, the participants indicated they found the re-designed method clear and logical. The different stages are fundamentally different and therefore well distinguishable. In stage 1 there was a discussion about the difference between the purpose, need, goal and main question of the analysis and the consistency in which this is applied throughout the method. The participants are very positive about stage 2. The template provided is very clear and the keywords added to each source of uncertainty are very useful. In stage 3 there is some discussion about the uncertainty/impact matrix and how to evaluate uncertainty. On participant suggests exchanging the uncertainty axis for 'plausibility' or 'likeliness' of occurrence of the uncertainty. When defining the style of uncertainty here, the participants noticed the interpretation of reducible and irreducible uncertainty is a bit open and can influence how the identified uncertainties are defined. Participants share they find stage 4 clear. Stage 5 is also perceived as clear. At the end of the session, one participant shared they found the visual and storytelling process overview of the method (with the towers) very clear and this helped them to understand how the method works and what they were doing. The other participant indicated the threshold to apply the method to a product development project is low, especially compared to a previous version of the method, due to the clear structure and easy usability.

Questionnaire

The questionnaire was constructed of both open and closed questions. The closed questions were answered on a 5-point Likert scale that can be found in Figure 7.2.B. The open questions will be discussed below.

Q2. How did you experience today's session in general? Please explain your answer.

In general, the participants experienced the user test very positively. During the session, the structure of the method was the main focus, rather than the project-specific content discussion. This allowed for critical reflection on the form and logic of the method. The different steps of the method were identified as logical and relevant.

Q4. Follow up on question 3.

The participants had a good understanding of the work they were doing during the session. The stages were clear and well-aligned with the goal of the method. However, for one participant there was some confusion about the impact/uncertainty matrix in stage 4, where they recommended replacing uncertainty with plausibility, and the interpretation of reducible and irreducible uncertainty in stage 4.

Q6. Follow up on question 5.

Both the participants shared they understand the method very well. The stages are clearly distinguishable, and the structure and process of the method are well visualized and explained. One participant shared that the principles used in the method become more clear to them now they have experienced them a second time.

Q13. In case you want to elaborate on any of the provided statements (questions 7-12) to clarify your answer, please do so here.

One respondent shared they experienced the method as very well structured. This ensures the process is very complete and gives them the confidence they executed the method correctly. They do believe some of the principles used can be made a bit more clear to prevent misinterpretation (e.g. reducible and irreducible uncertainty).

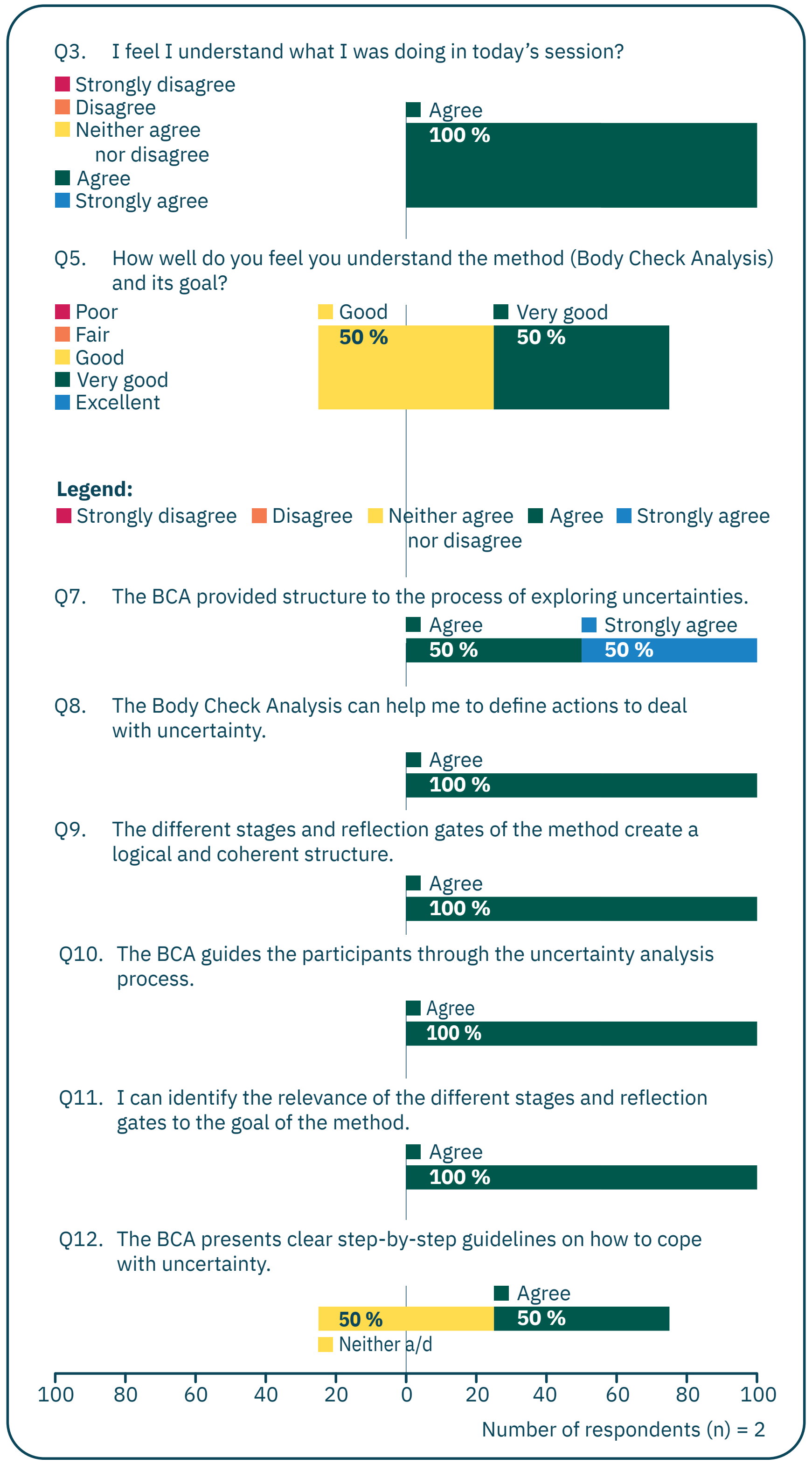


Figure 7.2.B - Responses from the questionnaire of the user test. The questions were answered on a 5-point Likert scale. The answer options for the questions are shown on the left side for question three and five, or in the legend for the other questions. The graph presents the total percentage of each provided answer. The third answer option (yellow) out of 5 is fitted in the centre of the axis.

Q14. In what ways should the BCA be used within Nedap? Please explain your answer.
Both participants shared the method would be most valuable to apply for new propositions at Nedap. They expect that applying the method for these product development projects will provide the most new insights that can be used in the development process. On of the reasons it could be used is to help determine whether a project can be scaled to a new product development phase. One respondent shared they wonder whether the method would also be valuable to apply for existing propositions that are already well established in the market. They were unsure whether the BCA would still deliver major new insights after a proposition has already been in development for a long time, and if this would be worth the time-investment to execute the method.

Q15. If the BCA was applied outside of Nedap or new product development, for what purpose should it be used? Please explain your answer.
Both participants shared they believe all organisations in product development that experience uncertainty could benefit from applying the Body Check Analysis. One respondent believed that outside of product development, other corporate processes subject to uncertainty might also benefit from applying the Body Check Analysis.

Q16. Is there anything else you would like to share?
One respondent indicated consistency in the use of terminology could still be improved (e.g. purpose, goal, and uncertainty). Other than that, they believe the Body Check Analysis is most valuable to apply in the starting phase of a project (at around 3 to 6 months in a project).

Concluding the user test

The goal of the user test was to test the method for its usability and functionality. During this evaluation, the main focus was on investigating the structure and logic of the method, the relevance of the different stages and gates to the goal of the method and how well this is communicated to the users, and the usability of the method.

Participants experienced the method as well structured, clear and logical. The five different stages are fundamentally different and therefore well distinguishable. Moreover, the relevance of the different stages and reflection gates to the goal of the method could be well identified. This was largely due to the overview that explained the process of the analysis in a visual and storytelling way. The structure of the method ensures the process is very complete and gave the participants the confidence they executed the method correctly. This structure, in combination with the templates which increased the usability of the method, also ensured the threshold to apply the method is low. However, it could also be recognised some of the principles used can be made a bit more clear to prevent misinterpretation and incorrect use (e.g. reducible and irreducible uncertainty, and the uncertainty/impact matrix in stage 3). Next to this, the consistency in the used terminology throughout the method could be improved (e.g. different reflection gates refer to either the purpose, goal or main question of the analysis).

When reflecting on the application of the Body Check Analysis, both participants believed the method would be most valuable when applied in the starting phase of the product development process of new propositions. For example after 3 to 6 months. They expect that applying the method for these product development projects will provide the most new insights that can be used in the development process. When applying the method later in the product development process, they were unsure whether the BCA would still deliver major new insights after a proposition had already been in development for a long time. Another possible application for the method would be to help determine whether a project can be scaled to a new product development phase. The method could also benefit other organisations in product development that experience uncertainty or could potentially be applied outside of product development to other corporate processes subject to uncertainty.

7.3 Assessment of the requirements

In this section, the final design of the method is assessed based on the presented requirements. In the second design cycle, a reflection on the requirements was already presented. Hence, this section will highlight the main developments apart from providing a complete assessment. Input for this assessment is the case study executed in the second design cycle and the user test conducted in the third design cycle.

When reflecting on the main goal of the method as formulated in the stated purpose, it can be recognised the BCA can largely fulfil this goal (also see Table 7.3.A). The BCA enables the identification of uncertainties, analyse their potential impact on the product development project, and aid in selecting suitable approaches to deal with the uncertainty. The stated purpose also presented a desire for a future-driven approach that helps in exploring future challenges to examine their potential relationship with the project and identify accompanying opportunities and risks. Although the final design helps to examine the external environment at present-day for challenges and identify accompanying opportunities and risks, it places less emphasis on this future-driven desire. A previous design in the second design cycle had a future-driven focus. However, it was recognised this made the method too complex and caused amongst others the method to be unfit for Nedap. This complexity issue has been tackled in the third design cycle and resulted in a clear, well-structured and logical method that shows value to the product development process at Nedap. In Table 7.3.A, an assessment of each of the requirements is presented. The main developments compared to the 'Reflection on the requirements in chapter 6.3' have been highlighted.

Table 7.3.A – Assessment of the functional requirements. The main developments compared to the 'Reflection on the requirements in chapter 6.3' have been highlighted.

	The method should…	
1	**Knowledge generation**	Reflection
A	…aid identification of uncertainties	Yes, The BCA aids very well in the identification of uncertainty and examining the source from which the uncertainty is emerging. **The wheel of uncertainty in stage 2 largely contributes to the identification and examination.**
B	…support scanning of external developments and identify their relation to the product development	Partly, the BCA aids in scanning the external environment for developments through the use of the wheel of uncertainty in stage 2 of the BCS, however, in some cases, it was difficult to identify the relationship between external developments and the proposition.
C	…aid in examining the potential impact of uncertainties on product development	Yes, the BCA aids in evaluating the impact of uncertainties on the product development process. **Especially in stage 3, where the identified uncertainties are evaluated for their relative uncertainty and impact, the potential impact is investigated.**
D	…aid in exploring future challenges and identifying accompanying opportunities and risks	No, the method does not explicitly support exploring future challenges and identifying accompanying opportunities and risks. **However, they were able to examine the external environment at present-day for challenges and identify accompanying opportunities and risks.**
E	…aid in selecting approaches to cope with the identified uncertainty	**Yes, the BCA aids in defining approaches to cope with the identified uncertainty. This is done in stage 4, where the action plan is defined**.
F	…help in identifying crucial decisions	No, the BCA does not specifically help in identifying crucial decisions. However, it does help in identifying the most important uncertainties and the decisions that need to be made in order to cope with those. **This is done in stage 3, where the identified uncertainties are evaluated for their uncertainty and impact to define the core uncertainties (i.e. the most important uncertainties).**
2	**Usability**	
A	…increase the ability of designers to control uncertainty	Yes, most participants agreed that working with the BCA increased their ability to control uncertainty in product development. **Making uncertainty explicit through identification and following this identification up by defining a concrete action plan helped to create this level of control.**
B	…be suited to the product development process of Nedap	**Yes, the BCA shows potential value to the product development process at Nedap and is suited to the use context. The clear structure of the method ensures the process is very complete and gives users the confidence they execute the method correctly. This high usability creates a low threshold to apply the method and makes it suitable for the use context.**
C	…be clear how and when to use the method in the product development process	**Yes, for participants it is clear both how and when the method can be used in the product development process. The starting phase of the product development process for new propositions is believed to be the most valuable application. The guidebook helps to explain how the method can be applied.**
D	…provide structure to the process of exploring uncertainties	Yes, participants were conclusive that the BCA provided structure to the process of exploring uncertainties. **The fundamentally different stages provide clear actions that need to be executed in the process of exploring uncertainties.**
E	…guide the users through the uncertainty analysis process	**Yes, the BCA guides the users through the uncertainty analysis process. Especially the templates provide clear instructions.**
F	…be suited to the decision-making process of Nedap	Yes, by embedding the action plan into the way of working at Nedap **in stage 4 of the method**, any decisions that need to be made as an outcome of the BCA are aligned with the decision-making process at Nedap.

chapter 8

Concluding the research

This research developed an approach to aid the decision-making process for product development at Nedap to cope with uncertainty, this resulted in the Body Check Analysis method. In this chapter, the discussion, conclusions and recommendations are presented.

Discussion

Considering uncertainty in product development is essential and can greatly benefit the product's success. This research investigated the field of uncertainty and product development and determined how an approach can be developed to aid the decision-making process in product development to cope with uncertainty. The iterative design approach used in this thesis is not only characteristic of product development but also for coping with uncertainty. Its process is complex, multifaceted and subject to vagueness. Most importantly, the process of coping with uncertainty highly benefits from a learning process. As discussed in the preliminary research, understanding uncertainty and coping with it requires comprehending a variety of theories, principles and skills. Not only related to uncertainty itself but also adjacent domains. Especially in the process of uncertainty identification, a certain affinity with one or more sources of uncertainty is very useful. Hillson (1997) and Terje Karlsen (2011) presented four attributes to assess the maturity level of an organisation in effective management of uncertainty. It can be recognised that the designed Body Check Analysis only contributes to one of these attributes, namely, process. However, frequent and steady use of the method throughout an organisation can help in building towards the other attributes; consistent application, building experience, and creating a supportive organisational culture. Also, Rice et al. (2008) underline the importance of a learning process in dealing with (high) uncertainty in combination with a plan or method to support this approach.

Integrating the Body Check Analysis into the organisation at Nedap can be done by embedding its application in the product development workflow as already suggested. In other words, during the fuzzy front end of NPD, or for Nedap specifically, at the end of the 'exploration' stage or the start of the 'create' stage in proposition development. For example, a specific milestone can only be achieved when the method is executed. However, consistent application of the BCA alone does not yet fully create a learning process. Therefore, a feedback loop is required where the learnings and new insights are communicated and recorded for a future application of the BCA or product development activities in general. For example, if consistent application of the BCA shows 'competitors need to be monitored more closely', or 'include business partners into the product development process' as reoccurring response actions, such a recorded feedback loop can identify this pattern. Subsequently, these actions could be included on a general basis in the product development process to strengthen these identified weaknesses. Apart from a feedback loop, operational support needs to be embedded that assists designers and decision-makers in executing the BCA and maintaining the recorded feedback. This research showed coping with uncertainty can be a complicated process.

This research investigated the relationship between uncertainty and new product development and confirmed the fuzzy front end of NPD to generally hold the highest degree of uncertainty as discussed in the investigated literature (du Preez & Louw, 2008; Herstatt et al., 2004; Jetter, 2003; Lindemann & Lorenz, 2008; Sperry & Jetter, 2009). As decisions made in this phase of product development largely determine the costs, quality and time frame of the project, coping with uncertainty, or reducing uncertainty here is critical. Participants in the user test also believed the Body Check Analysis would be most valuable when applied in the starting phase of new product development. This is a logical statement considering the research by Herstatt et al. (2004) that identified the fuzzy front end as the greatest weakness in NPD. However, the research also presented a dissimilarity between the investigated literature and the practical examination in the expert interviews. Jetter (2003) shows how the uncertainty in the product development process and product life cycle fluctuates, however, also gradually reduces over time. In the findings of the expert interviews, within the 'propositions' decision-making process, the uncertainty fluctuates as well, however, does not significantly reduce over time. Although this difference could be explained by a variation between the perception of the degree of uncertainty present (as explained by the interviewee) and the actual degree of uncertainty present, it also highlights a gap in the existing research. Investigating the development of uncertainty throughout the product development process and product life cycle can help in identifying the sources of uncertainty and the degree of uncertainty present at distinct phases in these processes. Moreover, it can show what activities or (external) developments typically bring uncertainty. This knowledge could help in selecting uncertainty-coping approaches or product development activities that are suitable for specific product development or product lifecycle phases. Or at least ensure these approaches or activities are available within the organisation if needed. Following Courtney et al. (1997), not all approaches to cope with uncertainty are appropriate to apply in all situations, or some will even be deemed ineffective in some cases.

There are a variety of approaches available that can help in coping with uncertainty as discussed in the preliminary research of this thesis. However, it can be recognised there is a gap between the product development process itself and these approaches. Existing approaches either fail to create a strong connection to the product development process (to ensure alignment between the in- and outputs of the combined processes), or require uncertainty to already be identified. The design proposed in this thesis – the Body Check Analysis – addresses this gap by 1) setting goals from the perspective of the product development objectives, 2) performing uncertainty identification, 3) integrating the defined action plan into the product development process, and 4) monitoring the effectiveness of the action plan. The use case walkthrough, case study and user test each highlighted the importance of a strong connection between the product development process and the uncertainty coping method. There must be a strong identifiable relevance between the method and its activities and the product development process. Possibly, the BCA could be applied in combination with other existing approaches as long as this connection is safeguarded. For example, when further in-depth analysis is required after evaluating the identified uncertainties, simulation or scenario planning could be applied. However, it should be investigated how these different approaches could be combined and integrated into the product development process. This research showed that the integration of scenario elements to cope with uncertainty in product development at Nedap can be challenging.

The research presented is subject to two clear limitations, that each relate to the generalizability of the research. The evaluation of the BCA in this research shows the designed method can fulfil its goal to aid the decision-making process for product development at Nedap to cope with uncertainty. Hence, this evaluation primarily focuses on testing the efficacy (i.e. getting things done) and the effectiveness (i.e. doing the right things) by applying the BCA in a real-world situation (i.e. the case study). However, the research did not investigate the impact of applying the BCA on the entire development process of a design project. It could be argued that applying the BCA at the front end of the development process can increase product development success; reducing uncertainty in this part of the development process contributes to creating a higher success according to Herstatt et al. (2004). However, the research could not confirm this.

Next to this, the method has been applied to only one innovation project at Nedap for evaluation. Although the characteristics of the innovation project chosen for the evaluation are typical for NPD, which was an important factor in choosing the innovation project for the evaluation; the innovation project can be classified as an evolutionary innovation following the work by Lynn & Akgün (1998), Meldrum & McDonald (1995), Nelson et al. (2013); the research did not investigate the applicability and validity of the design in product development organisations outside of Nedap.

Conclusions

This thesis was driven by two main research goals. Firstly, creating an understanding of uncertainty itself and the role uncertainty plays in product development. This goal is addressed in preliminary research by studying the existing research available related to uncertainty and product development and investigating the relationship between uncertainty and product development at Nedap through expert interviews. Secondly, developing an approach that Nedap can apply to cope with uncertainty in the decision-making process of product development. This goal is targeted by transforming the created understanding of the first goal into a practical application; the Body Check Analysis. The method is designed, evaluated and assessed in three design cycles. Here, amongst others, the method is applied in a case study to one of the innovation projects at Nedap.

It can be concluded the designed Body Check Analysis can aid the decision-making process in product development at Nedap to cope with uncertainty. On a practical level, the BCA provides a structured method to identify uncertainty in the product development process, explore its potential impact, and define ways to deal with it. This increases the ability of designers to control uncertainty and minimise its negative impact on product development. Consistent application of the method through a learning process can help Nedap in building towards a greater maturity level in managing uncertainty. Here, it is important to focus on gaining experience in dealing with uncertainty. This will help to build knowledge and skills to cope with uncertainty throughout the organisation and create a more uncertainty-aware mindset. Moreover, it is essential to make use of the existing supportive organisational culture at Nedap. Ensuring commitment, time, and resources are made available to apply methods such as the Body Check Analysis is part of this. A first step can be taken by embedding the application of the BCA in a gate or milestone in the fuzzy front end of the product development process for new products (i.e. propositions).

The qualitative evaluation of the Body Check Analysis in the case study and user test showed the method primarily helped participants by providing a tool to identify and reduce uncertainty. It helped to, more objectively than is done now, determine uncertainty and support the discussion on how to assess and approach these. By applying the BCA on a larger scale through a learning process, it can help to facilitate this discussion on an organisational level. Moreover, it could aid in identifying general weaknesses in the product development process as stated in the discussion.

Although uncertainty is vastly investigated in organisational and strategical decision-making, research on uncertainty in product development and design is less available, despite its high negative impact. On an academic level, this research contributed to the field of uncertainty in NPD by investigating the development of uncertainty throughout the product development process. The expert interviews provided a valuable mechanism for determining how and when to integrate a method to cope with uncertainty. The fuzzy front end of NPD can benefit most from the application of such a method, right after the completion of the first product exploration (e.g. around 3-6 months). Performing the initial exploration helps to define a stronger project scope and allows the execution of a more focussed BCA.

Next to this, the research investigated the development of a method to cope with uncertainty in product development at Nedap. This process learned a strong connection between the method and the product development activities is vital for the success of the method. Hence, the different steps in the method need to have a high recognisable relevance to the product development process at the organisation. Not only does this help to integrate the outcome of the method into the NPD process, but also to increase the usability of the method.

Recommendations

The recommendations of this thesis will be presented next. These are categorized into recommendations more specifically for Nedap and recommendations that are related to general future research.

Recommendations for Nedap

The Body Check Analysis provides a method to aid Nedap in the decision-making process of product development to cope with uncertainty. As addressed in the discussion, this research evaluated the BCA through application at one of the innovation projects at Nedap. Although the chosen innovation project is characteristic of innovation projects in NPD and the evaluation should give a fair reflection, it is recommended to validate the BCA with different innovation projects and users at Nedap. This investigation will help to identify further challenges and opportunities in the implementation of the BCA at Nedap.

Although this research investigated the relationship between uncertainty and product development and used the theory on the maturity level to select a design scope, it did not investigate the maturity level in uncertainty management in the entire organisation of Nedap. As can be recognised in the expert interviews and literature, product development is not an isolated process. It is connected to many other processes within an organisation, for example, strategy development. Hence, it is valuable to investigate the maturity level in uncertainty management at Nedap to identify growth opportunities. This can be done by applying the theory from Hillson (1997) and Terje Karlsen (2011) as discussed in the preliminary research of this thesis. Here, they introduce four attributes that can be used to assess the maturity level; process, application, experience, and culture. For each of these attributes should be investigated to what extend they are present within the organisation. Then, this information can be used to determine the maturity level in uncertainty management at Nedap; 1) naïve, 2) novice, 3) normalized, or 4) natural. Finally, the outcome of this assessment can be used to identify the discussed growth opportunities and will highlight what attributes should be focussed upon to build towards a higher maturity level.

To implement the Body Check Analysis in the product development process and to build towards a higher maturity level in managing uncertainty, it is recommended to develop a learning plan (i.e. learning process) for uncertainty thinking, as addressed by Rice et al. (2008). The focus of this learning plan lies in creating a supportive structure and feedback systems. The supportive structure in the form of a team or oversight board guides the application of the BCA, the learning trajectory of (product development) personnel, and creates tools for the learning process. The feedback systems should enable communication and record the learnings and new insights for a future application of the BCA or product development activities in general. For example, ‘How can we use the generated knowledge from this BCA execution in a future BCA or product development project?’. Creating a link between the feedback systems and the product lifecycle management systems can help to align these different processes. Here, the action plan of the BCA could be embedded to support informed decision-making. The BCA should be part of the learning plan, however, as addressed in the previous paragraph, the learning plan can also be open to other approaches and methods to cope with uncertainty (in different professions in Nedap).

The preliminary research of this thesis also identified simulation and scenario planning approaches as valuable practices for coping with uncertainty. The research by Van der Duin (2006) proposes a future-audit that provides a source of inspiration for innovation projects and a tool to evaluate whether new ideas are in line with future scenarios and trends. As presented in the introduction, societal developments and challenges add to the uncertainty experienced in NPD. As uncertainty is not only related to the probability of occurrence of certain events and developments but also how they will develop, a future-audit could provide an additional framework to cope with uncertainty in product development. This will help to test the ‘future-proofness’ of innovation projects and inform strategical decision-making. Uncertainty analysis, such as the BCA, can be applied as part of this future-audit. It is recommended to investigate the application of such a future-audit for product development at Nedap.

Future research recommendations

The research discussed is subject to two clear, but related, limitations: 1) the impact of applying the BCA on the entire development process of a design project, and 2) the applicability and validity of the BCA in product development organisations outside of Nedap. To address these limitations, it is recommended that the Body Check Analysis is evaluated with different innovation projects across different product development organisations to investigate its success and impact in the long-term.

This thesis identified a gap in the existing research about the development of uncertainty throughout the product development process and product lifecycle. It is recommended to further investigate this to identify the sources of uncertainty and the degree of uncertainty present at distinct phases in these processes. It can show what activities or (external) developments typically bring uncertainty. This will help to select product development activities and uncertainty-coping approaches that are suitable for specific product development or product lifecycle phases. This investigation could be executed in the form of interviews across various product development organisations and disciplines within their product development and innovation departments, as was done in the expert interviews. Here, it is vital to create tools that minimize bias and allow the generated results to be comparable to each other.

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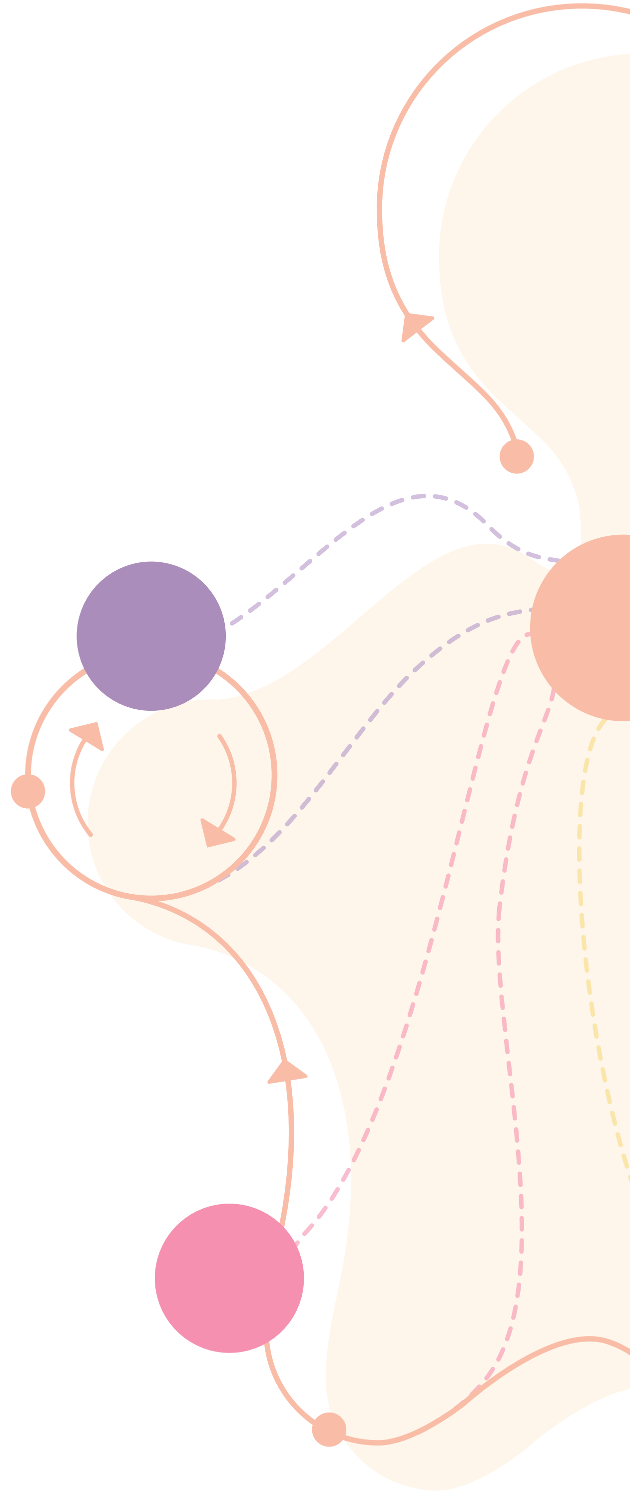


Appendix

Appendix A.1 Explanation for each of the sources of uncertainty

Table A.1.A – Explanation for each of the sources of uncertainty based on the research of De Weck et al. (2007), Jetter (2003), Lasso et al. (2020) and Rice et al. (2008).

Uncertainty source	Description
Technology	'Technological uncertainty' mainly arises due to uncertainty about technological feasibility and readiness, and relates to how well the underlying technical or scientific knowledge of the product is understood. Especially applying novel or not yet existing technologies (or technologies that are new to the company) – of which little to no information about their performance is known at the time of product definition – contribute to this uncertainty. Also, the reuse of existing technology components creates uncertainty. Components that work well in some products, might not perform well in other products, due to differences in demand, use context, or unmodelled interactions between different parts of the product. The reliability and durability of a component are also affected by this. However, when only utilizing existing technologies, opportunities offered by more advanced technologies might be missed, or the organisation could risk offering non-competitive products compared to companies that do adapt more advanced technologies (De Weck et al., 2007; Jetter, 2003; Lasso et al., 2020; Rice et al., 2008). **Keywords**: technology, reliability, durability, interactions **Example**: A lack of knowledge on the reliability of a product part, or unknown interdependencies between different product parts (Lasso et al., 2020).
Organisational	'Organisational uncertainty' describes the deficiency between the capabilities of an organisation and its needs, and relates to the organisational dynamics. Changing development teams (or internal partners), inconsistency or lack of definition in expectations and strategic commitments, or an undefined relationship between the operating team and the rest of the organisation contribute to this uncertainty (De Weck et al., 2007; Lasso et al., 2020; Rice et al., 2008). **Keywords**: organisational context, operating team, strategy **Example**: Implementing a new way of working, unclear commitment from management towards the project activities, changing project goals or planning.
Resource allocation	'Uncertainty about resource allocation' describes the uncertainty experienced in deciding how many resources to allocate to a project, when to allocate these and the lack of understanding about the continuity of these resources. In this context, resources can be financial, material or competence-based (Jetter, 2003; Lasso et al., 2020; Rice et al., 2008). **Keywords**: finances, materials, competencies **Example**: Unavailability or fluctuations in funding or materials. Lack of competencies in the project team that are essential to the success (Lasso et al., 2020; Rice et al., 2008).

Table A.1.A – (continued) Explanation for each of the sources of uncertainty based on the research of De Weck et al. (2007), Jetter (2003), Lasso et al. (2020) and Rice et al.

Use context	'Uncertainty about the use context' describes the uncertainty experienced in how a product will be used and in what conditions it will operate. When the operating environment of the product changes, reliability for different climates, weather conditions, or terrains is required. Moreover, the skills and experience of (different) operators can add to this uncertainty, for example when a maintenance contract is changed (De Weck et al., 2007). **Keywords**: use context, operating environment, reliability, maintenance, operator (end-user) skills and experience **Example**: Unclear or changing use-environment, wrong predictions about the level of skill and experience of operators. The United States of America M1 Abrams tank was originally designed during the Cold War in the 1980s to be used in moderate climates in central Europe, however, it unexpectedly ended up being used during the 2000s in the Middle East. Sand clogged up the machinery, causing the parts to fail much quicker than anticipated. This drained the availability of spare parts and the profitability of signed service contracts (De Weck et al., 2007).
Partners	'Uncertainty about partners' arises due to uncertainty about the business context and collaborations. Changes in the business context can significantly influence how a product is developed or operated, or the viability of a product solution (within a specific market) altogether (De Weck et al., 2007). **Keywords**: partners, business context, collaboration, contractual agreements **Example**: Lack of knowledge about the business context. An undefined (contractual) agreement under which the product is designed (De Weck et al., 2007).
Suppliers	'Supplier uncertainty' mainly arises due to uncertainty about the supply chain. Unclear contractual agreements or fluctuations in the delivery of materials and components can significantly influence the viability of a product solution. In some cases, they may even require changes to existing designs. **Keywords**: suppliers, supply chain **Example**: Lack of knowledge and understanding of supply chains and suppliers. Political conflicts can hinder the production or shipment of materials and components, creating material scarcity. But also accidents (e.g. blocked ship on the Suez Canal) can prevent a reliable source of materials and components. Changing exchange rates may increase the costs of manufacturing, or the ability to sell products in certain regions abroad (De Weck et al., 2007).

Table A.1.A – (continued) Explanation for each of the sources of uncertainty based on the research of De Weck et al. (2007), Jetter (2003), Lasso et al. (2020) and Rice et al.

Competitors	'Competitor uncertainty' describes the uncertainty experienced by existing and new competitors. They could create new products that can threaten the success of existing products or new product development activities. Next to this, also identifying the potential of certain parties to become a competitor contributes to this (Jetter, 2003). **Keywords**: competition, new product development **Example**: Lack of knowledge about the development activities in the market and the relationship between these. The incapability of identifying parties as (potential) competitors. In the 1990s the Low Earth Orbit Satellite Constellations Iridium and Globalstar were pioneers in the mobile space-based telephony. In spite of their astonishing technological developments, their product solutions failed in the market. In contrast to their expectations, the market for wireless telephony was conquered by ground-based competitors. The mobile space-based telephony systems turned out to be too inflexible to easily adapt to different needs in coverage or service (De Weck et al., 2007). In the mid-2000s, Apple introduced their innovative iPhone with internet-enabled mobile technology and a touchscreen. The previous market leader Nokia was never able to fully recover its market position. Which eventually resulted in its decline and sale to Microsoft (Derbyshire & Giovannetti, 2017).
Market	The 'market uncertainty' is mainly created due to uncertainty about future consumer requirements and needs, and future competition, and relates to how well markets are defined and understood. A long time between the initial product definition and product launch can increase this uncertainty. As consumer requirements might change, new competitors could arise, or existing competitors could introduce new or improved products. How fast and strong markets change also depends on the nature and life span of the product (e.g. the fashion design market tends to change faster than the aircraft manufacturing market) (De Weck et al., 2007; Jetter, 2003; Lasso et al., 2020; Rice et al., 2008). **Keywords**: consumer requirements and needs, competition **Example**: The inability to anticipate future user groups during the product development process (Lasso et al., 2020). In the 1980s IBM greatly underestimated the market for personal computers and retreated from a market that became 100 times larger than the company's forecasts (Polasky et al., 2011).

Table A.1.A – (continued) Explanation for each of the sources of uncertainty based on the research of De Weck et al. (2007), Jetter (2003), Lasso et al. (2020) and Rice et al.

Politics & regulations	'Uncertainty about politics and regulations' relates to the wider political forces that influence the market. These can be translated into concrete uncertainties, such as changing regulations and political decisions. Regulations (i.e. legislation and directives) can require significant changes in both the operability of existing products and the development of new products. Moreover, countries can change their entire purchasing preference based on political decision-making and policy changes. But also political activities such as conflicts and war may change market conditions (De Weck et al., 2007). **Keywords**: politics, regulations, legislation **Example**: Lack of knowledge about political activities and (upcoming) regulations. Tightened regulations for the diesel engine industry require car manufacturers to develop new technological solutions for both new diesel engines and diesel engines used in existing vehicles. During unpopular actions by the United States of America (USA) government (e.g. Iraq war), US truck manufacturers experience significant dips in their sales (De Weck et al., 2007). Environmental protection legislation restricts the production of a (new) product (Jetter, 2003). For example, as of July 2021, single-use plastics, products made out of oxo-degradable plastic, and food and beverage containers made out of expanded polystyrene are no longer allowed to be put on the markets of EU Member States (European Commission, Directorate General for Environment, 2021).
Culture & society	'Uncertainty about culture & society' describes the wider cultural and societal forces, norms and values that influence the market. These values and forces can influence entire lifestyle, purchasing or political preferences of social groups or countries. Prices for goods are in many industries dictated by demand and supply, rather than just the production costs. Changing values or crises can influence the demand for goods, pushing the financial viability of product solutions or creating entirely new markets (De Weck et al., 2007). **Keywords**: culture, norms, values, economy, crisis **Example**: Lack of knowledge about norms and values, or general cultural understanding. Due to decreasing popularity of smoking – caused by the Dutch tobacco control policy (Willemsen, 2017) – Tembo modified their cigar production machinery to produce paper pots, used for growing and seeding plants (Tembo Group B.V., 2023).
Natural environment	'Uncertainty about the natural environment' arises due to uncertainty about geological formations, weather phenomena, natural disasters, and climate (i.e. natural events). Especially for industries that extract natural resources this is important. The natural environment can not only affect organisations and products directly, but also indirectly through affecting global supply chains, or through environmental protection legislation (De Weck et al., 2007; Jetter, 2003). **Keywords**: nature, geology, weather, climate, natural disasters, natural resources **Example**: Lack of knowledge and understanding about environmental conditions and their potential implications when these change. Increasing drought during the summer hinders the production of agricultural goods.

Appendix A.2 The levels of uncertainty by Courtney et al. (1997)

Level 1: A Clear-Enough Future

Description: At this first level, the decision-maker(s) can create a forecast of the future that is clear enough for decision-making. The outcome of a decision can be predicted or understood with small tolerances for uncertainty. There is no need to consider uncertainty-related risks, as the uncertainty itself is trivial and irrelevant to making decisions (Courtney et al., 1997; Helmrich & Chester, 2022).

Example: A franchise chain in hearing aids is considering opening new stores for the distribution of its product. The accompanying uncertainties and risks are well understood and can be calculated. Demographic research can help select what regions show the greatest potential for the sales of hearing aids (i.e. the number of elderly people in a region in relation to those that require hearing aids) (Vries, de & Toet, 2022).

Toolbox for analysis: No scenarios, instead, the 'Traditional' strategy tool kit can be applied; market research, competitors' cost and capacity analysis, risk assessment, life cycle assessment, Michael Porter's five forces framework, etc. (Courtney et al., 1997; Helmrich & Chester, 2022).

Level 2: Alternate Futures

Description: At the second level, discrete scenarios or alternate futures can describe the future. Analysis cannot help establish which of the potential outcomes will occur, however, it can help to evaluate the probability and plausibility of each scenario. To make the best decisions, each plausible scenario needs to be evaluated for trade-offs, and probabilities, risks and consequences for events need to be considered (Courtney et al., 1997; Helmrich & Chester, 2022).

Example: Changing regulations within a stable market. These changing regulations (e.g. environmental regulations or laws) can have a major impact on new investments (Vries, de & Toet, 2022).

Toolbox for scenario analysis: Develop discrete scenarios describing alternate futures, based on the understanding of how the key uncertainties could play out. These scenarios can also be described as 'What if?' scenarios (e.g. what if competitor A builds a new plant, or what if not?). Other tools that can be used to help evaluate the scenarios are game theory & decision analysis. In addition to this, also tools from the 'Traditional' strategy tool kit can be applied; market research, competitors' cost and capacity analysis, risk assessment, life cycle assessment, Michael Porter's five forces framework, etc. (Courtney et al., 1997; Helmrich & Chester, 2022; Vries, de & Toet, 2022).

Level 3: A Range of Futures

Description: At the third level, the future is described through numerous potential outcomes, captured on a range defined by a number of key variables. No discrete scenarios can be found at this level. To make decisions, decision-makers need to develop their own scenarios within the defined range for evaluation. One direct solution cannot be created, however, decision-makers can test the robustness of different solutions through scenarios. This approach allows one to become more adaptive and manage a broad range of different possible outcomes, instead of developing only one potential outcome (Courtney et al., 1997; Helmrich & Chester, 2022).

Example: An innovation company in the semiconductor industry decides to invest in a new technology. Or a European company considering introducing its products to the Indian market. After good market research, the potential market penetration rate is estimated from 10% to 30%. There are no discrete scenarios within this range, hence, it is difficult to choose just one strategy (Courtney et al., 1997).

Toolbox for scenario analysis: Develop scenarios that describe the extremes on a range of possible outcomes. Tools that can be used to support the analysis and evaluate the scenarios are scenario planning & technology forecasting (Courtney et al., 1997; Helmrich & Chester, 2022).

Level 4: True Ambiguity

Description: At the fourth level, the interaction between different sources of uncertainty develops an environment that practically cannot be predicted. Unlike the third level, identifying the range of possible outcomes and scenarios within that range is nearly impossible. Let alone defining the key variables that shape the future. For decision-making, decision-makers should identify elements they do know, those that can be learned, and those they cannot learn. By monitoring these elements, decision-makers can create incremental developments to their plans when certain knowledge becomes known. It is argued that situations at level 4 uncertainty are quite rare, and often transition to another level over time (Courtney et al., 1997; Helmrich & Chester, 2022).

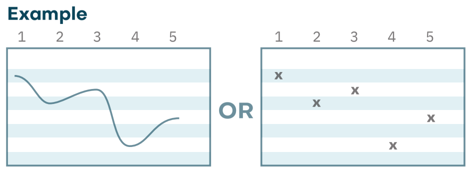
Example: Companies considering making large investments in post-communist Russia in 1992 experienced level 4 uncertainty. Not only little was known about the market situation and currency stability, but also the political situation (i.e. laws and regulations on property rights) could not be outlined (Courtney et al., 1997).

Toolbox for scenario analysis: Focus on defining variables that will determine how the market will develop over time, and what variables are favourable or unfavourable. Followed by tracking the development of the variables, and adapting the strategy based on these developments and the occurrence of new information. This can be done by systematically mapping what is known or could be known. Moreover, determining the most important characteristics and qualities of winners and losers, and identifying the strategies they used, can help select and apart the strategy. In time, a situation in level 4 uncertainty can migrate to for example level 3. Tools that can be used to support the analysis are pattern recognition, info-gap analysis, and adaptation pathways (Courtney et al., 1997; Helmrich & Chester, 2022).

Appendix A.3 Expert interviews

Likert scales design/development process

Example



Phase:

Uncertainty within a decision-making process

Extremely high	
Very high	
High	
Moderate	
Little	
Very little	
No	

Impact of the outcome of a decision-making process

Severe	
Major	
Significant	
Moderate	
Mild	
Minor	
None	

Frequency of a decision-making process

Daily	
Weekly	
Monthly	
Quarterly	
Once a year	
Once every 2 to 5 years	
Never	

Figure A.3.A – Template for the interview.

Table A.3.B - Rubric - Uncertainty within a decision-making process.

	No	Very little	Little	Moderate	High	Very high	Extremely high
Internal	No internal uncertainties are experienced.	Some internal uncertainties (1 or 2 types) are experienced, such as lack of insight of exact technological or hardware dimensions.	A few internal uncertainties (at least 2 types) are experienced, such as a *greater* lack of insight of exact technological or hardware dimensions, or lack of knowledge of the exact use context (i.e. operational environment or climate conditions)	A significant amount of internal uncertainties (at least 3 types) are experienced, such as a lack of insight of the exact resource allocation to a project or the team composition. Also a *greater* lack of insight of exact technological or hardware dimensions, or lack of knowledge of the exact use context is experienced.	A significant amount of internal uncertainties (3-4 types) are experienced, such as a *greater* lack of insight of company strategy, exact resource allocation to a project or the team composition. Also a *greater* lack of insight of exact technological or hardware dimensions, or lack of knowledge of the exact use context is experienced.	Many different types of internal uncertainties (at least 4 types) are experienced, *causing a great lack of insight on most factors*, such as an unclear or undefined company strategy, resource allocation, team composition, technological or hardware dimensions, or use context.	Many different types of internal uncertainties (at least 4-5 types) are experienced, *causing nearly no insight on nearly all factors*, such as a an extremely unclear or undefined company strategy, resource allocation, team composition, technological or hardware dimensions, or use context.
						It is sometimes unknown what is unknown	It is sometimes unknown what is unknown
External	No external uncertainties are experienced.	No external uncertainties are experienced.	Some external uncertainties (1 or 2 types) are experienced, such as a lack of insight of the exact market demand, or the economic scenario.	A few external uncertainties (at least 2 types) are experienced, such as a lack of insight of exact competitor actions. Also a *greater* lack of insight of the exact market demand, or detailed partner or supplier agreements is experienced.	A significant amount of external uncertainties (at least 3 types) are experienced, such as a lack of insight of cultural and societal acceptance, environmental conditions or the economic scenario. Also a *greater* lack of insight of the exact market demand/position, detailed partner or supplier agreements, or exact competitor actions is experienced.	Many different types of external uncertainties (at least 4 types) are experienced, such as a lack of insight of political situations or regulations. Also a *greater* lack of insight of cultural and societal acceptance, environmental conditions or the economic scenario, market demand/position, exact competitor actions, etc. are experienced.	Many different types of external uncertainties (at least 4-5 types) are experienced, *causing a great lack of insight on most factors*, such as political situations or regulations, cultural and societal acceptance, environmental conditions or the economic scenario, market demand/position, exact competitor actions, etc.

Table A.3.C - Rubric - Impact of the outcome of a decision-making process.
The table below shows some examples (both positive and negative) of impacts [consequences of a decision] on internal or external factors. Some examples could fit into multiple columns, depending on the perspective from which they are reviewed.

	None	Minor	Mild	Moderate	Significant	Major	Severe
Internal - examples	The decision made does not have any impact on internal factors.	The decision has a minor impact on internal factors… NEG: …causing some frustration, discomfort or a bit of extra work for a few individuals. POS: …causing a relief in workload for a few individuals, opening time for other projects/tasks.	The decision has a mild impact on internal factors… NEG/POS: …causing changes in the development team.	The decision has a moderate impact on internal factors… NEG/POS: …causing the change of management/ operational strategy (way of working) within a market group	The decision has a significant impact on internal factors… NEG: …causing no focus on multiple projects, a delay in the development of a product, the cancellation of a contract with a partner, or the discontinuation of a proposition.	The decision has a major impact on internal factors… NEG: …causing insufficient funds for development, or the cancellation of a contract with a partner. POS: …causing a rapid large increase of market value for the company.	The decision has a severe impact on internal factors… NEG: …causing no income for the entire organisation, or bankruptcy.
External - examples	The decision made does not have any impact on external factors.	The decision has a minor impact on external factors… NEG/POS: …causing a change in focus to only develop software products. POS: …causing to increase efficiency in production on a few farms.	The decision has a mild impact on external factors… NEG: withdrawal from a market (i.e. pigs).	The decision has a moderate impact on external factors… NEG/POS: …causing the bankruptcy of one or more competitors in one or more market.	The decision has a significant impact on external factors… NEG/POS: …causing the creation of a new market regime (new type of market), i.e. smartphones, microwaves.	The decision has a major impact on external factors… NEG: …causing the death of a few animals. POS: …causing net-zero emission dairy production.	The decision has a severe impact on external factors… NEG: …causing a natural disaster. POS: …causing worldwide dairy production through efficient protein production (zero emissions).

Appendix A.4 First design cycle

1.

Start 1 - Scope Setting

Design brief formulation:
- Define purpose of the analysis;
    - What is the need?
    - What is the main question that needs to be answered?
- Describe the main actors and stakeholders.
- Describe the company's identity, core-competences and characteristics;
    - e.g. risk-tolerance/appetite.
- Define the temporal and spatial scope of the analysis.

Goal: Create focus & apply framing.

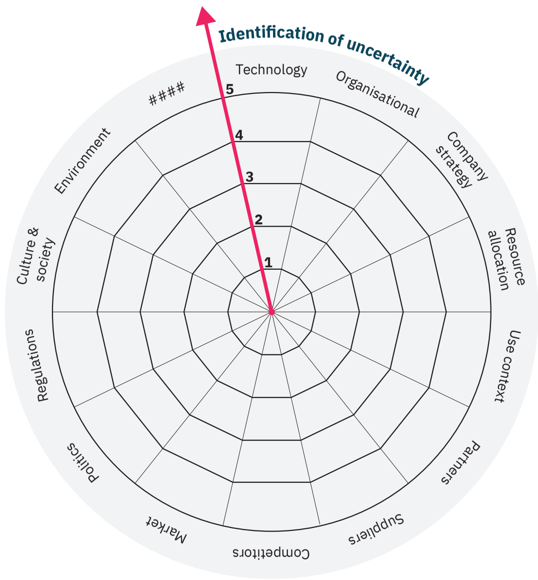
Assign a 'Gatekeeper'.

2.

2 - Identification of uncertainty

Identify for each **type** the **degree** in which uncertainty is encountered.

1 = absolute certainty
5 = absolute uncertainty



3.

3 - Defining causes of uncertainty

Explaining the causes of uncertainty for each type through the three perspectives; *state, effect*, and *response* (Jetter, 2003).

- Provide evidence and/or reasoning for the explanation.
- Assess quality of the explanation.

State: The environment (or a part of it, such as a technology or competitor) is perceived to be unpredictable.
- *How well do we understand the environment itself?*

Effect: There is an inability to assess the impact of environmental changes (e.g. withdrawal of competitor from the market).
- *How well do we understand the impact or consequences of environmental changes?*

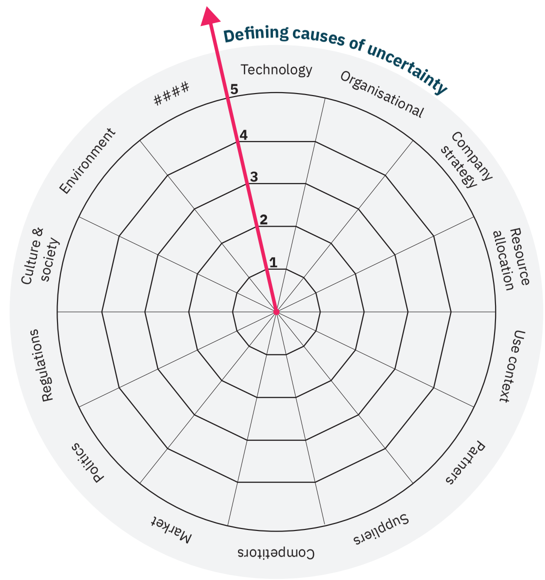
Response: There is a lack of information on response actions themselves and their possible effects (e.g. the opportunities and consequences of a novel technology). This type of uncertainty can also occur when the environment itself and causal relations are well understood.
- *How well do we understand the opportunities and consequences of response actions we can perform?*

How to fill in the causes on the radar?

1 = very good understanding; very high quality evidence, reasoning and explanation.

5 = very poor understanding; very low quality evidence, reasoning and explanation.

1. Fill in the radar seperately for *state* (***S***), *effect* (***E***), and *response* (***R***).
2. Take the average of the three perspectives.



4.

Reflection gate

'Does the identification of uncertainty match our explanation of the causes of the uncertainty?'

- Can the uncertainty be explained?
- Can we justify our *certainty* on a type of uncertainty?
    - Do we understand the cause well enough?
- Do the radars of *Identification of uncertainty* and *Defining causes of uncertainty* match?

5.

4 - Defining style of uncertainty

The style of uncertainty can be characterised in *reducible* and *irriducible* uncertainty (De Weck et al., 2007).

Reducible uncertainty relates to a lack of definition or lack of knowledge, and with additional effort this ambiguity or lack of knowledge can be reduced, as the issues are relatively well understood. Examples are the reliability of technical components, or corporate strategy and commitment.

Irreducible uncertainty can only be 'explained' by the occurrence of future events. Examples are the results of a sports match, or the value of a portfolio on the stock market in a year time.

Categorise the uncertainties identified in *reducible* and *irreducible*. This categorisation can help later in the process to assign response actions to specific uncertainties.

Reducible	Irreducible

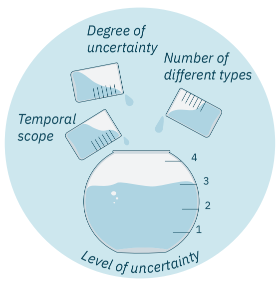
6.

5 - Planning scenario analysis

Depending on the total *degree of uncertainty* and *different types of uncertainty* experienced, and the *temporal scope*, the level(s) of uncertainty is/are defined; level 1, 2, 3 or, 4 (Courtney et al, 1997).

The level of uncertainty is a summation of the three parameters mentioned above and can be seen in the figure on the right. Use the next cards '*Scenario analysis || level 1 to 4*' to help determine the level of uncertainty.

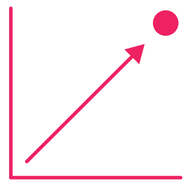
These cards will also provide direction in how the scenario analysis should be executed.



7. 5 - Scenario analysis || level 1

A Clear-Enough Future

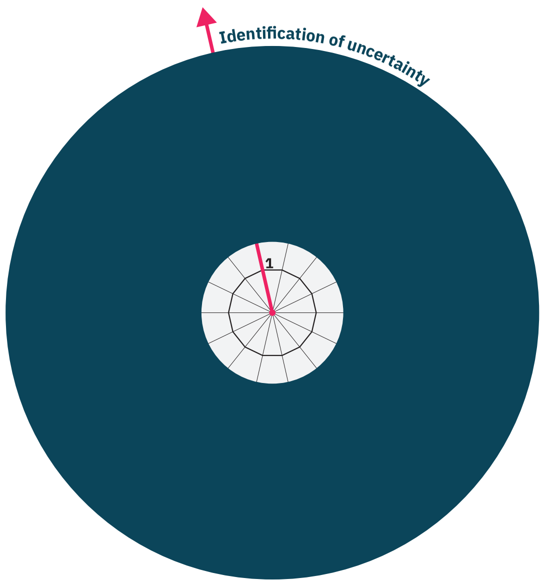
"The first level is a clear enough future (Level 1) where the decision-maker understands the outcome with small tolerances for uncertainty. In this stage, uncertainty is nearly negligible, and decision-makers do not need to consider the uncertainty-related risk involved." (Helmricht & Chester, 2022, p. 5)



Characteristics

Toolbox for scenario analysis
i.e. what scanerio analysis to use?

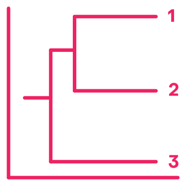
How to identify this level of uncertainty?



8. 5 - Scenario analysis || level 2

Alternate Futures

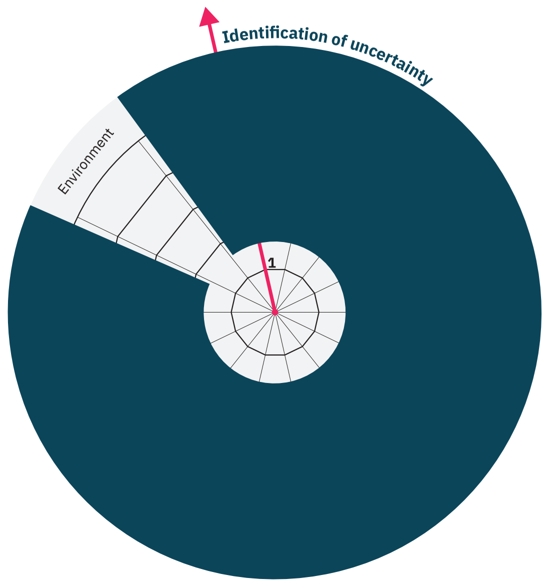
"At level 2, the future can be described as one of a few alternate outcomes, or discrete scenarios. Analysis cannot identify which outcome will occur, although it may help establish probabilities. Most important, some, if not all, elements of the strategy would change if the outcome were predictable." (Courtney et al., 1997, p. 4)



Characteristics

Toolbox for scenario analysis
i.e. what scanerio analysis to use?

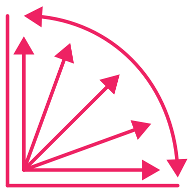
How to identify this level of uncertainty?



9. 5 - Scenario analysis || level 3

A Range of Futures

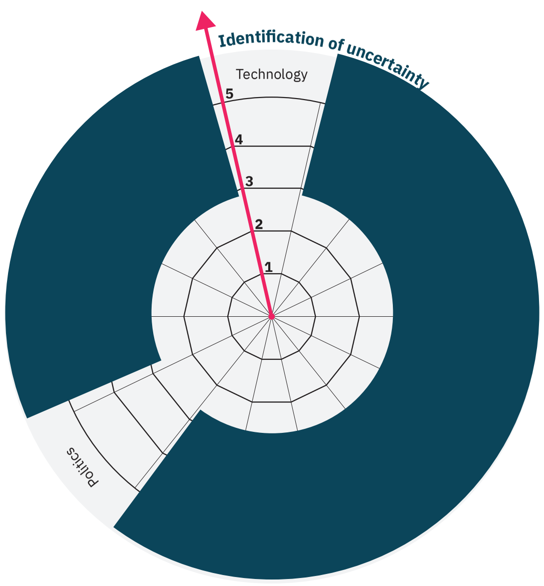
"At level 3, a range of potential futures can be identified. That range is defined by a limited number of key variables, but the actual outcome may lie anywhere along a continuum bounded by that range. There are no natural discrete scenarios. As in level 2, some, and possibly all, elements of the strategy would change if the outcome were predictable." (Courtney et al., 1997, p. 4)



Characteristics

Toolbox for scenario analysis
i.e. what scanerio analysis to use?

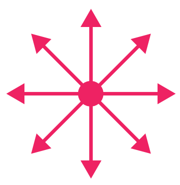
How to identify this level of uncertainty?



10. 5 - Scenario analysis || level 4

True Ambiguity

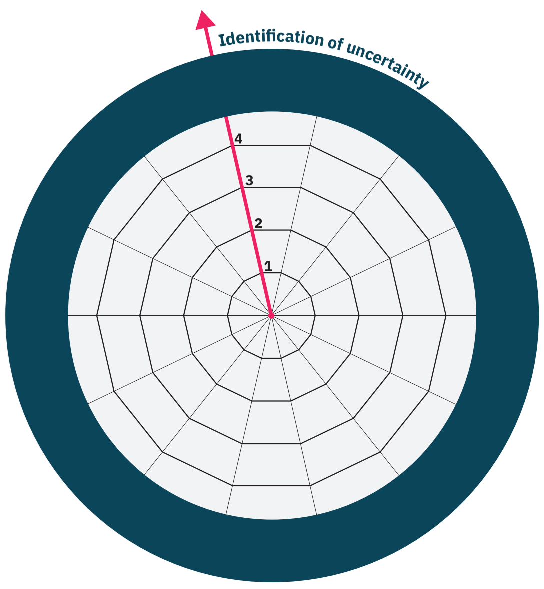
At level 4, multiple dimensions of uncertainty interact to create an environment that is virtually impossible to predict. Unlike in level 3 situations, therange of potential outcomes cannot be identified, let alone scenarios within that range. It might not even be possible to identify, much less predict, all the relevant variables that will define the future. (Courtney et al., 1997, p. 4-5)



Characteristics

Toolbox for scenario analysis
i.e. what scanerio analysis to use?

How to identify this level of uncertainty?



11.

Reflection gate

'Does the identified level of uncertainty, and the accompanying type of (scenario) analysis, match the design brief and the purpose of the uncertainty analysis?'

- Can the recommended type of (scenario) analysis help us gain the required knowledge to answer our questions?

12.

6 - Executing scenario analysis

The scenario approach matching the defined level(s) of uncertainty is/are executed.

The cards '*Scenario analysis || level 1 to 4*' can will provide direction in how the scenario analysis should be executed.

13.

Reflection gate

'Does the executed (scanerio) analysis generate the required knowledge to answer our questions?'

- Does the executed analysis match the purpose of the analysis and needs as described in the *design brief?*

14.

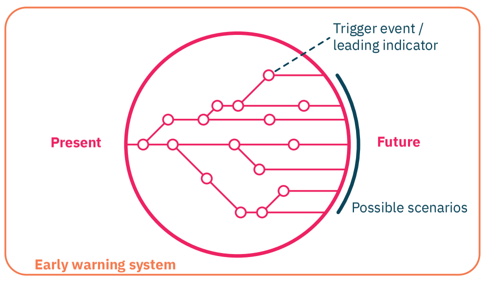
7 - Planning response actions

Defining trigger events, leading indicators, and early warning systems; systems that help indicate what 'design-actions' should be done when.

1. Perform (backcasting) analysis to define trigger events\leading indicators and create an early warning system.
2. Match trigger events to type of response action.
3. Embed the early warning system into the organisation's way of working.

What are trigger events or leading indicators?

The strength of an early warning system is to help explain the probability of a scenario over time, and monitor changes and developments in the identified uncertainties. Trigger events or leading indicators are the factors within this system that explain the probability or direction of a scenario. Hence, when specific trigger events are happening, they can be used to engage specific response actions (Vries, de & Toet, 2022). The figure below shows the relationship between trigger events, scenarios and the early warning system.



15.

Reflection gate

'Do the defined response actions match the purpose of the analysis and needs as described in the design brief?'

- Do the defined response actions match the identified trigger events, leading indicators, or early warning systems?
- Can the defined response actions be monitored as part of the way of working of the organisation?

16.

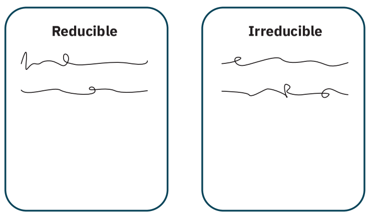
4 - Defining style of uncertainty

The style of uncertainty can be characterised in *reducible* and *irridcible* uncertainty (De Weck et al., 2007).

Reducible uncertainty relates to a lack of definition or lack of knowledge, and with additional effort this ambiguity or lack of knowledge can be reduced, as the issues are relatively well understood. Examples are the reliability of technical components, or corporate strategy and commitment.

Irreducible uncertainty can only be 'explained' by the occurrence of future events. Examples are the results of a sports match, or the value of a portfolio on the stock market in a year time.

Categorise the uncertainties identified in *reducible* and *irreducible*. This categorisation can help later in the process to assign response actions to specific uncertainties.



17.

8 - Executing response action & monitoring

Execute the defined response actions.

- Monitor the environment to watch for the activation of trigger events, leading indicators, or early warning signs. Followed by the execution of the appropriate response action.
  - Monitoring should be embedded into the organisation's way of working.
- When conditions have changed drastically, making the scenarios and/or response action planning invalid, restart uncertainty analysis.

18.

Reflection gate

'Do the response actions have the intended effect and address the initial purpose of the analysis and needs as described in the design brief?'

- How effective are the response actions?
- Are the scenarios and/or defined response actions / early warning system still valid, considering changing conditions?
  - Should (a part) of the uncertainty analysis be redone?

Appendix A.5 Second design cycle

Journal

Case study **Date:**

Name:

Write down in the journal any striking thoughts and experiences you encounter during the case study session. These thoughts and experiences can be related to any doubts or difficulties you experience but also insights you have gained during the session. Moreover, you can also use this paper as your notepad.

Insights I have gained during this session! (e.g. hey, this is something new I learned; this aspect of the Body Check Analysis makes sense; this knowledge is important to remember for my own work)

Doubts and difficulties I experienced during this session? (e.g. this part of the Body Check Analysis is unclear to me; for me, this task was difficult to work on; for this activity, I am doubting whether I am doing the right thing)

Other notes

Questionnaires

In this section, the questions asked in the questionnaire will be shown. At the start of each questionnaire, the following introduction was given:

"First of all, thank you for participating in this case study! The purpose of this case study is two-fold. Firstly, it aims to test and validate the developed Body Check Analysis (BCA) that I have created as part of my Industrial Design Engineering master's thesis. Secondly, reflect on the proposition - Innovation project at Nedap - from a broader perspective to support future decision-making in the proposition's development.

The goal of my thesis is to develop a method to support the decision-making process in product development and innovation, taking into account the uncertainties and complexities (future) developments can bring.

Over the course of four sessions, the case study will be executed. In each session, one or more stages of the Body Check Analysis will be treated:

- Stage 1 – Scope setting
- Stage 2 – Identification of uncertainty
- Stage 3 – Defining the cause of uncertainty
- Stage 4 – Defining style of uncertainty
- Stage 5 – Planning scenario analysis
- Stage 6 – Executing scenario analysis
- Stage 7 – Planning response actions
- Stage 8 – Executing response actions & monitoring

In this questionnaire you will be asked about your experiences in working with the Body Check Analysis applied during the case study. Please explain your answers clearly!

You are asked to fill in your name, so the results of the questionnaires of each session can be linked to one another. After completion of all the case studies, the results as the outcome of the questionnaires and case study will be processed anonymously.

If you have any questions about the case study or would like to know more about my research, let me know!"

Questions for Workshop 1	Formatting
1. What is your name?	Open question
2. How did you experience today's session in general? Please explain your answer.	Open question
3. How well do you feel you understand the method (Body Check Analysis) and its goal? a. Poor – Fair – Good – Very good – Excellent	Closed question with a 5-point Likert scale
4. I feel I understand what I was doing in today's session. a. Strongly disagree – Disagree – Neither agree nor disagree – Agree – Strongly agree	Closed question with a 5-point Likert scale
5. Please explain your previous answer.	Open question
6. How well are you able to identify the relevance of the work you did in today's session towards the overall goal of the Body Check Analysis? a. Poor – Fair – Good – Very good – Excellent	Closed question with a 5-point Likert scale
7. Please explain your previous answer. If you were able to identify the relevance, could you explain what this relevance is?	Open question
8. Do you feel you can identify the relevance of the work you did in today's session towards the overall goal for the 'Innovation project at Nedap' proposition? a. Poor – Fair – Good – Very good – Excellent	Closed question with a 5-point Likert scale
9. Please explain your previous answer. If you can identify the relevance, could you explain what this relevance is?	Open question
10. Is there anything else you would like to share?	Open question

Questions for Workshop 2	Formatting
Questions 1 until 9 are the same as asked in the questionnaire of workshop 1.	
10. There was a logical relationship between the different stages and gate during this session (stage 2: identification of uncertainty; stage 3: explaining the cause of uncertainty; and reflection gate yellow). a. Strongly disagree – Disagree – Neither agree nor disagree – Agree – Strongly agree	Closed question with a 5-point Likert scale
11. Please explain your answer. Is there anything that could have strengthened this relationship more?	Open question
12. Is there anything else you would like to share?	Open question

Questions for Workshop 3	Formatting
Questions 1 until 9 are the same as asked in the questionnaire of workshop 1.	
10. There was a logical relationship between stage 5 - Planning exploration analysis - and the red reflection gate during this session. a. Strongly disagree – Disagree – Neither agree nor disagree – Agree – Strongly agree	Closed question with a 5-point Likert scale
11. Please explain your answer. Is there anything that could have strengthened this relationship more?	Open question
12. Is there anything else you would like to share?	Open question

Questions for Workshop 4	Formatting
Section 1 – Introduction	Open question
1. What is your name?	Open question
2. What is your educational background?	Open question
3. How would you describe your role within Nedap?	Open question
4. Which of the workshops did you attend? a. 4th of July – Core Team – Stage 1: Design Brief b. 10th of July: Kick-off – Extended team – Stage 2+3: Uncertainty identification c. 13th of July – Extended team – Stage 4+5+6: Defining core uncertainties d. 20th of July – Extended team – Stage 7+8: Making an action plan	Closed multiple choice question – Multiple answers possible
Section 2 – About today's session These questions concern the workshop of today where we worked on the final stages of the Body Check Analysis.	
5. How did you experience today's session in general? Please explain your answer.	Open question
6. I feel I understand what I was doing in today's session. a. Strongly disagree – Disagree – Neither agree nor disagree – Agree – Strongly agree	Closed question with a 5-point Likert scale
7. Please explain your previous answer.	Open question
8. How well do you feel you understand the method (Body Check Analysis) and its goal? a. Poor – Fair – Good – Very good – Excellent	Closed question with a 5-point Likert scale
9. Please explain your answer. What could be done to improve this?	Open question
10. How well are you able to identify the relevance of the work you did in today's session towards the overall goal of the Body Check Analysis? a. Poor – Fair – Good – Very good – Excellent	Closed question with a 5-point Likert scale
11. Please explain your previous answer. If you were able to identify the relevance, could you explain what this relevance is?	Open question
12. Do you feel you can identify the relevance of the work you did in today's session towards the overall goal for the 'Innovation project at Nedap' proposition? a. Poor – Fair – Good – Very good – Excellent	Closed question with a 5-point Likert scale
13. Please explain your previous answer. If you can identify the relevance, could you explain what this relevance is?	Open question
Section 3 – About the entire method (1/2) These questions concern the entire Body Check Analysis (also referred to as BCA, or method) that has been executed during the case study of 'Innovation project at Nedap' in multiple workshops. Please answer these questions to the best of your ability. For the following questions, please indicate your level of agreement with the given statements below about the Body Check Analysis.	
14. The Body Check Analysis aids in the identification of uncertainties.	Closed question with a 5-point Likert scale ○ Strongly disagree ○ Disagree ○ Neither agree nor disagree ○ Agree ○ Strongly agree
15. The BCA helps to identify the sources from which uncertainty is emerging (e.g. through uncertainty identification in the wheel of uncertainty).	
16. The method aids in scanning external developments (e.g. through uncertainty identification in the wheel of uncertainty).	
17. The method aids in identifying the relationship between external developments and product development (i.e. the proposition 'Innovation project at Nedap').	
18. The Body Check Analysis aids in selecting approaches to deal with the identified uncertainties.	
19. After having worked with the BCA, I feel my ability to deal with uncertainty in product development has increased.	
20. The BCA provided structure to the process of exploring uncertainties.	
21. The BCA guided the participants through the uncertainty analysis process.	
Section 4 – About the entire method (2/2)	
22. How did working with the BCA influence your view on uncertainty in product development?	Open question
23. In what way(s) does the Body Check Analysis provide value to product development at Nedap?	Open question
24. After having worked with the BCA, what have you learned?	Open question
25. When reflecting on the entire process, what parts of the method (e.g. stages, reflection gates) provided the **most valuable** contribution to the entire process?	Open question
26. When looking back on the entire process, what parts of the method (e.g. stages, reflection gates) provided the **least valuable** contribution to the entire process?	Open question
Section 5 – Closing question	
27. Is there anything else you would like to share? Or do you have any suggestions?	Open question

Observation form

Case study **Date:** **Name observer:**

Write down in the observation form any striking experiences or events you notice during the case study session. These observation can be related to how the participants behave, and their interaction with the method – the Body Check Analysis, see the observation form below.

Goal of the case study: 1) Test and validate the developed Body Check Analysis, 2) Reflect on the [innovation project at Nedap] proposition from a broader perspective to support future decision-making in the proposition's development, and create a more flexible and robust product development decision-making process.

Topic	Notes
1) Participant behaviour: A. What activities, steps and workflow are participants concerned with? B. What do participants do similar and different to other participants? C. When interrupted – what caused this + what does the participant do next?	
2) **Reactions and mood changes** throughout the session.	
3) Interaction with the method BCA: A. In what ways do the participants interact with the Body Check Analysis? B. When and how do participants believe they completed a task or goal? C. What happens when participants believe they failed a task or activity? D. What touchpoints do the participants use to interact with the method?	

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Uncertainty Thinking

Body Check Analysis

Guidebook

Thomas G. J. Goudsblom

nedap

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Colophon

Uncertainty Thinking
The Body Check Analysis Guidebook

An uncertainty analysis method to aid decision-making in product development to cope with uncertainty.

Author
Thomas G. J. Goudsblom
Version October 2023

This document is part of the Industrial Design Engineering Master's thesis of the author; *Goudsblom, T.G.J. (2023). Uncertainty Thinking: Embracing uncertainty in product development.*

To execute the method - Body Check Analysis - four templates are available in addition to this guidebook.

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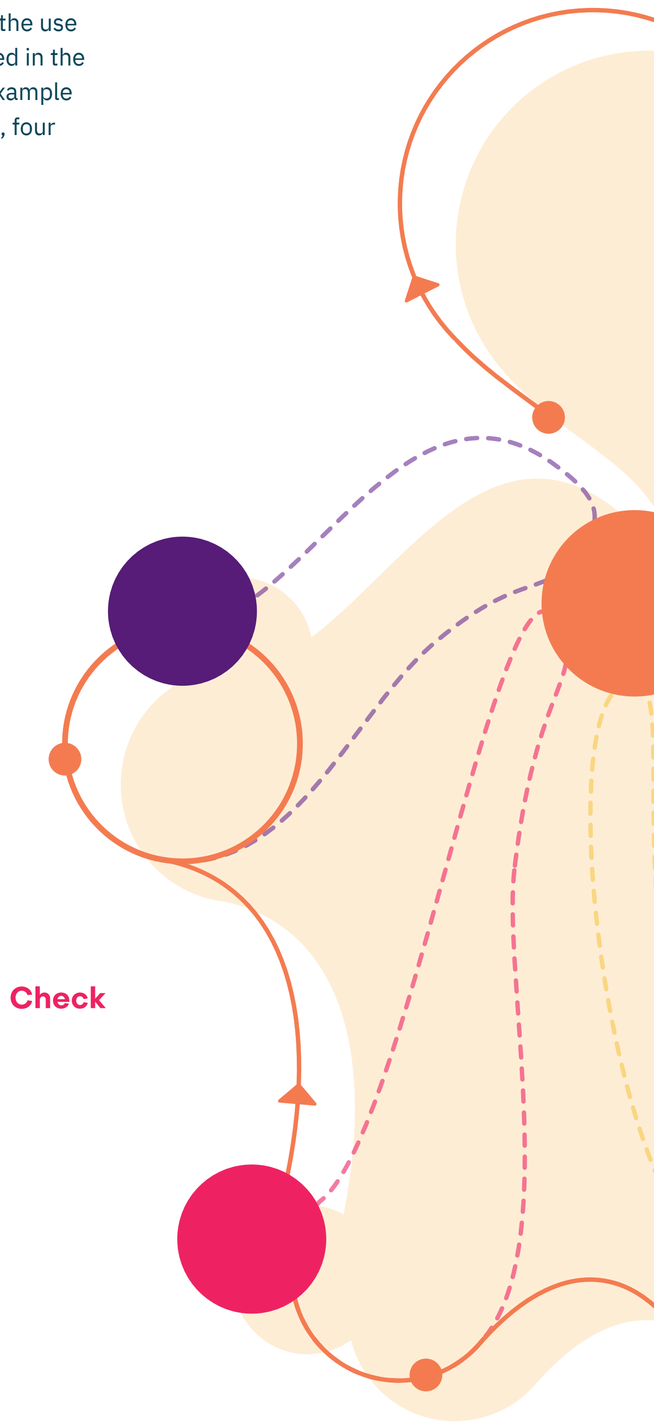
This guidebook presents a method - The Body Check Analysis - that helps designers and decision-makers gain more control over uncertainty in product development by aiding the decision-making process to cope with uncertainty. This is done by identifying uncertainty in the product development process and defining approaches on how to deal with these uncertainties through the use of the Body Check Analysis. In this guidebook, the relevant theory used in the method is discussed, the Body Check Analysis is presented, and an example is given of how the method can be used. In addition to this guidebook, four templates are provided to support the execution of the method.



1. Why consider uncertainty?

1.1. Why should uncertainty be considered in product development?

New product development (NPD) is an important process for companies, as it helps to, if successful, ensure future revenue and keep the product portfolio up-to-date. However, a high degree of uncertainty is also very distinctive for NPD. This does not only impact the behaviour of people in engineering design work itself but also has a negative overall impact on the NPD performance by "making activities and decisions more challenging" (Lasso et al., 2020, p. 3). Consequently, it also negatively impacts the quality of design decisions made. Therefore, for designers, it is important they are able to deal with uncertainty or seek to control uncertainty to a certain extent (Beheshti, 1993). By reducing the risk and uncertainty in the front end of the process and ensuring less variation from front-end specifications during the entire project execution, a higher product development success can be created (Herstatt et al., 2004).

From the past decades, numerous examples can be recognised of how uncertainty impacts the overall performance of an organisation, and how different approaches in coping with uncertainty can change this impact. Polasky et al. (2011), show examples of two major corporations and how their different approaches to dealing with uncertainty changed the impact on their organisation:

> *"During the 1980s, IBM did not use scenario planning and, as a result, greatly underestimated the market for personal computers. The company retreated from a market that became more than 100 times larger than its forecasts [32]. By contrast, Shell used scenarios to evaluate long-term decisions. Even though oil prices were low in 1970 and predicted to remain so, scenario planners from Shell considered alternate states, including some in which a consortium of oil-producing countries limited production and drove oil prices upward. Shell hedged against this case by changing its strategy for refining and shipping oil. This exercise in scenario planning allowed Shell to adapt more rapidly than its competitors to price increases during the mid-1970 s and it rose to become the second largest oil company in the world [33]." (Polasky et al., 2011, p. 401)*

As the example already shows, within the decision-making process some decisions have a higher significance and are more impactful than others. Derbyshire & Giovannetti (2017), describe these types of decisions as crucial decisions, as they tend to "change the very circumstances in which the decision is taken in the first place, such that no future decision can ever be made in the same circumstances again" (p.335). Moreover, they are also likely to invoke highly unpredictable responses from competitors, that can lead to numerous changes over a long time, and are indeterministic of character. Below is an example of a few crucial decisions and the extreme impact they can cause can be seen:

> *"Apple successfully innovated touchscreen and internet-enabled mobile technology, introducing their highly-innovative iPhone product in the mid-2000s (Mazzucato, 2015). As a result, the previously-dominant market-leader, Nokia, never fully recovered its market position, resulting in its decline and eventual sale to Microsoft. The correct decisions leading to the creation of a product with strong capabilities in relation to touchscreen and internet-enabled technology, made by Apple, and the incorrect decisions, or failure to make similar decisions in time, by Nokia, forever changed the strategic landscape of the mobile-phone market, such that no future decision could be made under similar circumstances again." (Derbyshire & Giovannetti, 2017, p. 336)*

Although a logical response to the consequences of a high degree of uncertainty in NPD would be to aim to fully eliminate uncertainty in the design process, in reality, this is either not possible or doing so would completely constrain the effectiveness of decision-making. Instead, using approaches that help to cope with or reduce the uncertainty, or minimize the impact of uncertainty on design decisions would work much better (Beheshti, 1993; Sniazhko, 2019).

1.2. What is uncertainty?

Before discussing how to cope with uncertainty, first, it should be discussed more in-depth what uncertainty is. As one might recognise, the concept of uncertainty is quite amorphous and expresses a certain degree of vagueness (Thunnissen, 2003), or indefiniteness (Lasso et al., 2020). As uncertainty is the origin of risk, applying a method to cope with uncertainty allows to examine the root-cause of both concepts and define ways to deal with them. Based on a literature review (De Weck et al., 2007; Herstatt et al., 2004; Lasso et al., 2020; Sniazhko, 2019; Thunnissen, 2003; Wynn et al., 2011), the following definition of uncertainty can be used:

> *Uncertainty describes a deficiency between the amount and quality of information in possession, and the amount and quality of information required to make a decision or to perform a specific task. Moreover, it also describes the presence of unknown information that could have a strong impact on the future state of a product, system or strategy and its success.*

On the right, in addition to the definition of uncertainty, the definitions of two related concepts can be found; 'riks' and 'impact'.

Reoccuring terminology in the Guidebook

Uncertainty describes a deficiency between the amount and quality of information in possession, and the amount and quality of information required to make a decision or to perform a specific task. Moreover, it describes the presence of unknown information that could have a strong impact on the future state of a product, system or strategy and its success.

Risk describes "an uncertain event or condition that, if it occurs, has a positive or negative effect on a project objective. A risk has a cause and, if it occurs, a consequence." (Project Management Institute, 2000, p. 127). For example, the cause may be labour shortage, the risk event is that there is no adequate labour for the task, and the consequence may be delayed project planning. The origin of risk can be found in the uncertainty that is present in all projects (Project Management Institute, 2000; Ward & Chapman, 2003). Whereas risk describes the situation or condition under which all potential outcomes and their probabilities of occurrence are known to the decision-maker, uncertainty describes the situation where such information is (partly) unknown to the decision-maker. This includes not only the outcome and probability of occurrence of a situation or condition but also how a situation or condition will develop (Park & Shapira, 2017; Vries, de & Toet, 2022).

The **impact** describes a strong effect or influence that something has on someone, something or a situation (Cambridge Dictionary, 2023).

1.2.1. Shapes of uncertainty

Uncertainty comes in many different shapes and forms. To help understand how to identify and deal with uncertainty, an uncertainty taxonomy can be applied to map the broad spectrum of uncertainties, see Figure 1.2.1.A. De Weck et al. (2007), makes an important distinction between known and unknown uncertainty.

For known uncertainty, one (i.e. the organisation) is capable of recognising and identifying the presence of the uncertainty. This uncertainty can both be reducible and irreducible. Reducible uncertainty often relates to a lack of definition or lack of knowledge, and with additional effort, this ambiguity or lack of knowledge can be reduced, as the issues are relatively well understood. Examples are the reliability of technical components, or corporate strategy and commitment. Irreducible uncertainty can only be 'explained' by the occurrence of future events. Examples are the results of a sports match or the value of a portfolio on the stock market in a year.

For unknown uncertainty, one (i.e. the organisation) is not capable of recognising and identifying the presence of the uncertainty. Hence, it is also not possible to reduce the uncertainty. Although, these unknown facts might still have a strong impact on the future state of a product, system or strategy and its success. Here, the goal lies in first 'revealing' the uncertainties before any other actions can be taken. However, even after the best possible uncertainty analysis, some uncertainty may remain, called residual uncertainty (Courtney et al., 1997).

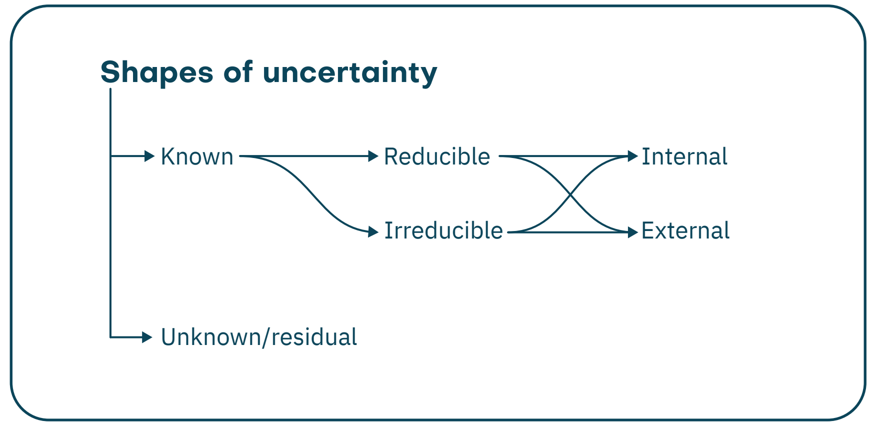


Figure 1.2.1.A - Taxonomy of the different shapes of uncertainty (De Weck et al., 2007; Courtney et al., 1997).

Next to the known and unknown uncertainty, De Weck et al. (2007), also describes the 'sphere of influence' or 'system boundary' to distinguish between internal and external sources of uncertainty, see Figure 1.2.1.B. Internal uncertainty arises from within the system (i.e. organisation), and can often be influenced by the designer of the organisation to a greater extent (e.g. the product or corporate context). External uncertainty arises from outside the system (i.e. organisation) and is often beyond the direct control of the designer and the organisation (e.g. the market, or environmental and political context). Not only does this help to build a basis for a taxonomy, but it also helps to gain more insight into the level of influence an organisation can have over certain uncertainties, find appropriate approaches to deal with these uncertainties and decide which uncertainties to focus on first.

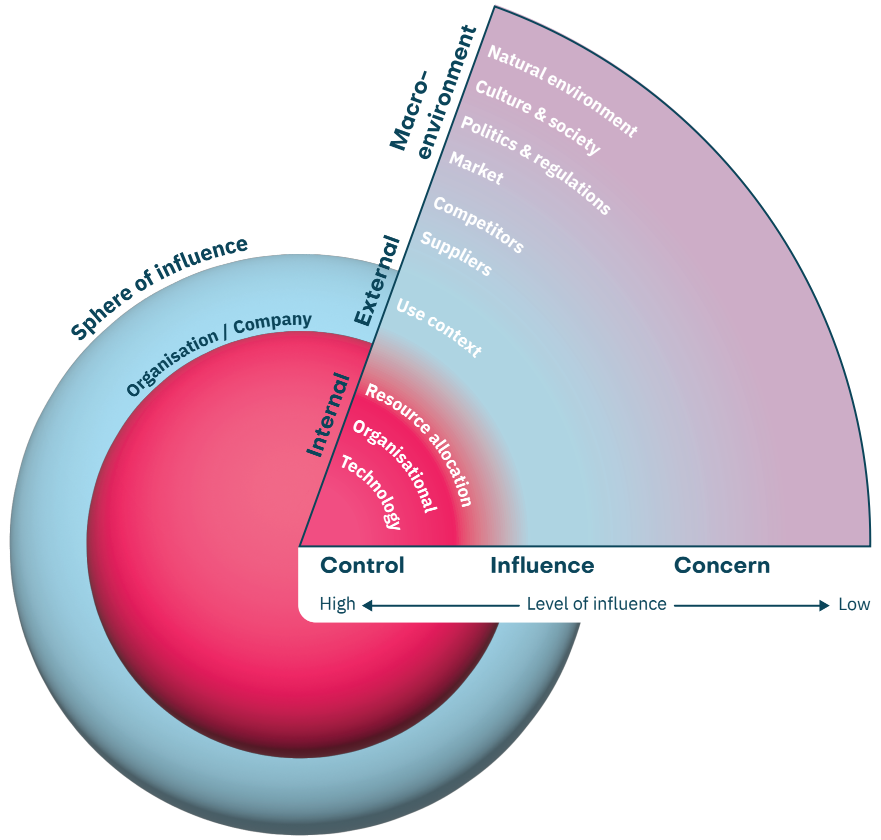


Figure 1.2.1.B - Sphere of influence. The sphere of influence showcases the level of influence an organisation can have over different sources of uncertainty (adapted from De Weck et al., 2007 and Haimes & Schneiter, 1996).

Open this fold-out page on the right bottom to view **Table 1.2.1A** for a description and examples of each of the sources of uncertainty.

1.2.2. The wheel of uncertainty

To help identify uncertainties, an overview of the most common sources of uncertainties can be used. The wheel of uncertainty, see Figure 1.2.2.A, shows 11 different sources of uncertainty that is developed based on a literature review (De Weck et al., 2007; Jetter, 2003; Lasso et al., 2020; Rice et al., 2008). Each of the sources of uncertainty is explained in Table 1.2.1.A. Next to the different sources, also the level of control over the different sources of uncertainty, as discussed by De Weck et al. (2007) (see section 1.2.1 and Figure 1.2.1.B), has been represented in the wheel of uncertainty .

It is important to note that multiple sources of uncertainty can interact with one another. In some instances, this will create an environment that is impossible to predict (Courtney et al., 1997). Nevertheless, it is crucial to examine potential relationships between sources of uncertainty. Sometimes it could seem a very high degree of uncertainty in multiple sources is experienced, while in reality the origin of the uncertainty can be traced back to one source (see Figure 1.2.2.B).

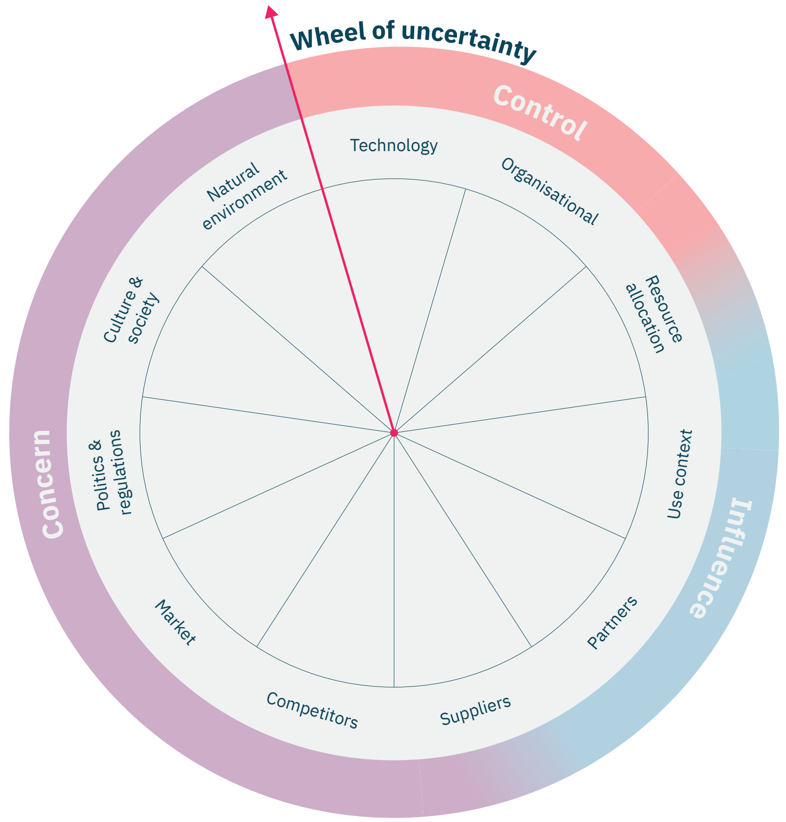


Figure 1.2.2.A - The wheel of uncertainty.

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Table 1.2.1.A - Sources of uncertainty. For each source of uncertainty a description, keywords, and an example are provided.

Uncertainty source	Description
Technology	'Technological uncertainty' mainly arises due to uncertainty about technological feasibility and readiness, and relates to how well the underlying technical or scientific knowledge of the product is understood. Especially applying novel or not yet existing technologies (or technologies that are new to the company) – of which little to no information about their performance is known at the time of product definition – contribute to this uncertainty. Also, the reuse of existing technology components creates uncertainty. Components that work well in some products, might not perform well in other products, due to differences in demand, use context, or unmodelled interactions between different parts of the product. The reliability and durability of a component are also affected by this. However, when only utilizing existing technologies, opportunities offered by more advanced technologies might be missed, or the organisation could risk offering non-competitive products compared to companies that do adapt more advanced technologies (De Weck et al., 2007; Jetter, 2003; Lasso et al., 2020; Rice et al., 2008). **Keywords**: technology, reliability, durability, interactions **Example**: A lack of knowledge on the reliability of a product part, or unknown interdependencies between different product parts (Lasso et al., 2020).
Organisational	'Organisational uncertainty' describes the deficiency between the capabilities of an organisation and its needs, and relates to the organisational dynamics. Changing development teams (or internal partners), inconsistency or lack of definition in expectations and strategic commitments, or an undefined relationship between the operating team and the rest of the organisation contribute to this uncertainty (De Weck et al., 2007; Lasso et al., 2020; Rice et al., 2008). **Keywords**: organisational context, operating team, strategy **Example**: Implementing a new way of working, unclear commitment from management towards the project activities, changing project goals or planning.
Resource allocation	'Uncertainty about resource allocation' describes the uncertainty experienced in deciding how many resources to allocate to a project, when to allocate these and the lack of understanding about the continuity of these resources. In this context, resources can be financial, material or competence-based (Jetter, 2003; Lasso et al., 2020; Rice et al., 2008). **Keywords**: finances, materials, competencies **Example**: Unavailability or fluctuations in funding or materials. Lack of competencies in the project team that are essential to the success (Lasso et al., 2020; Rice et al., 2008).
Use context	'Uncertainty about the use context' describes the uncertainty experienced in how a product will be used and in what conditions it will operate. When the operating environment of the product changes, reliability for different climates, weather conditions, or terrains is required. Moreover, the skills and experience of (different) operators can add to this uncertainty, for example when a maintenance contract is changed (De Weck et al., 2007). **Keywords**: use context, operating environment, reliability, maintenance, operator (end-user) skills and experience **Example**: Unclear or changing use-environment, wrong predictions about the level of skill and experience of operators. The United States of America M1 Abrams tank was originally designed during the Cold War in the 1980s to be used in moderate climates in central Europe, however, it unexpectedly ended up being used during the 2000s in the Middle East. Sand clogged up the machinery, causing the parts to fail much quicker than anticipated. This drained the availability of spare parts and the profitability of signed service contracts (De Weck et al., 2007).
Partners	'Uncertainty about partners' arises due to uncertainty about the business context and collaborations. Changes in the business context can significantly influence how a product is developed or operated, or the viability of a product solution (within a specific market) altogether (De Weck et al., 2007). **Keywords**: partners, business context, collaboration, contractual agreements **Example**: Lack of knowledge about the business context. An undefined (contractual) agreement under which the product is designed (De Weck et al., 2007).
Suppliers	'Supplier uncertainty' mainly arises due to uncertainty about the supply chain. Unclear contractual agreements or fluctuations in the delivery of materials and components can significantly influence the viability of a product solution. In some cases, they may even require changes to existing designs. **Keywords**: suppliers, supply chain **Example**: Lack of knowledge and understanding of supply chains and suppliers. Political conflicts can hinder the production or shipment of materials and components, creating material scarcity. But also accidents (e.g. blocked ship on the Suez Canal) can prevent a reliable source of materials and components. Changing exchange rates may increase the costs of manufacturing, or the ability to sell products in certain regions abroad (De Weck et al., 2007).

Table 1.2.1.A continued - Sources of uncertainty. For each source of uncertainty a description, keywords, and an example are provided.

Competitors	'Competitor uncertainty' describes the uncertainty experienced by existing and new competitors. They could create new products that can threaten the success of existing products or new product development activities. Next to this, also identifying the potential of certain parties to become a competitor contributes to this (Jetter, 2003). **Keywords**: competition, new product development **Example**: Lack of knowledge about the development activities in the market and the relationship between these. The incapability of identifying parties as (potential) competitors. In the 1990s the Low Earth Orbit Satellite Constellations Iridium and Globalstar were pioneers in the mobile space-based telephony. In spite of their astonishing technological developments, their product solutions failed in the market. In contrast to their expectations, the market for wireless telephony was conquered by ground-based competitors. The mobile space-based telephony systems turned out to be too inflexible to easily adapt to different needs in coverage or service (De Weck et al., 2007). In the mid-2000s, Apple introduced their innovative iPhone with internet-enabled mobile technology and a touchscreen. The previous market leader Nokia was never able to fully recover its market position. Which eventually resulted in its decline and sale to Microsoft (Derbyshire & Giovannetti, 2017).
Market	The 'market uncertainty' is mainly created due to uncertainty about future consumer requirements and needs, and future competition, and relates to how well markets are defined and understood. A long time between the initial product definition and product launch can increase this uncertainty. As consumer requirements might change, new competitors could arise, or existing competitors could introduce new or improved products. How fast and strong markets change also depends on the nature and life span of the product (e.g. the fashion design market tends to change faster than the aircraft manufacturing market) (De Weck et al., 2007; Jetter, 2003; Lasso et al., 2020; Rice et al., 2008). **Keywords**: consumer requirements and needs, competition **Example**: The inability to anticipate future user groups during the product development process (Lasso et al., 2020). In the 1980s IBM greatly underestimated the market for personal computers and retreated from a market that became 100 times larger than the company's forecasts (Polasky et al., 2011).
Politics & regulations	'Uncertainty about politics and regulations' relates to the wider political forces that influence the market. These can be translated into concrete uncertainties, such as changing regulations and political decisions. Regulations (i.e. legislation and directives) can require significant changes in both the operability of existing products and the development of new products. Moreover, countries can change their entire purchasing preference based on political decision-making and policy changes. But also political activities such as conflicts and war may change market conditions (De Weck et al., 2007). **Keywords**: politics, regulations, legislation **Example**: Lack of knowledge about political activities and (upcoming) regulations. Tightened regulations for the diesel engine industry require car manufacturers to develop new technological solutions for both new diesel engines and diesel engines used in existing vehicles. During unpopular actions by the United States of America (USA) government (e.g. Iraq war), US truck manufacturers experience significant dips in their sales (De Weck et al., 2007). Environmental protection legislation restricts the production of a (new) product (Jetter, 2003). For example, as of July 2021, single-use plastics, products made out of oxo-degradable plastic, and food and beverage containers made out of expanded polystyrene are no longer allowed to be put on the markets of EU Member States (European Commission, Directorate General for Environment, 2021).
Culture & society	'Uncertainty about culture & society' describes the wider cultural and societal forces, norms and values that influence the market. These values and forces can influence entire lifestyle, purchasing or political preferences of social groups or countries. Prices for goods are in many industries dictated by demand and supply, rather than just the production costs. Changing values or crises can influence the demand for goods, pushing the financial viability of product solutions or creating entirely new markets (De Weck et al., 2007). **Keywords**: culture, norms, values, economy, crisis **Example**: Lack of knowledge about norms and values, or general cultural understanding. Due to decreasing popularity of smoking – caused by the Dutch tobacco control policy (Willemsen, 2017) – Tembo modified their cigar production machinery to produce paper pots, used for growing and seeding plants (Tembo Group B.V., 2023).
Natural environment	'Uncertainty about the natural environment' arises due to uncertainty about geological formations, weather phenomena, natural disasters, and climate (i.e. natural events). Especially for industries that extract natural resources this is important. The natural environment can not only affect organisations and products directly, but also indirectly through affecting global supply chains, or through environmental protection legislation (De Weck et al., 2007; Jetter, 2003). **Keywords**: nature, geology, weather, climate, natural disasters, natural resources **Example**: Lack of knowledge and understanding about environmental conditions and their potential implications when these change. Increasing drought during the summer hinders the production of agricultural goods.

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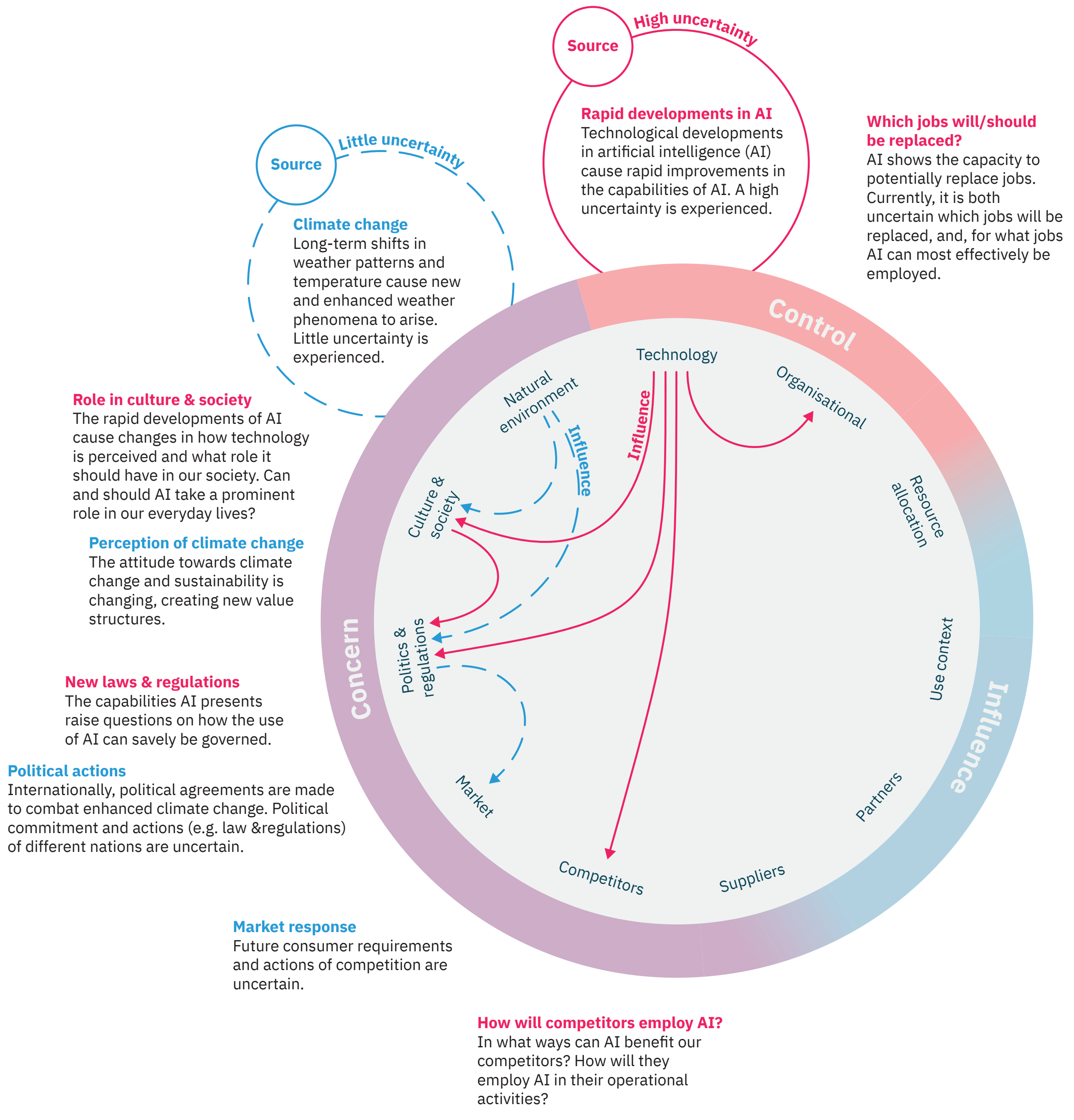

Figure 1.2.2.B - Relationship between different sources of uncertainty.

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1.3. How to respond to uncertainty?

Essential to the process of product development are designers, or more specifically, the decision-makers. They shape the problem-definition and guide the proposition through the innovation or product development process. Different postures can be taken towards uncertainty, and these highly influence how uncertainty can be coped with. Lipshitz & Strauss (1997), identified three basic postures towards uncertainty among people in decision-making; reducing, acknowledging and suppressing uncertainty. The applied posture can be dependent on both the working culture and the cultural background within an organisation. The working culture functions as an enabler to efficiently cope with uncertainty (Terje Karlsen, 2011), whereas the cultural background can influence the degree of uncertainty avoidance. This describes the extend to which people are able to tolerate uncertainty and ambiguity (Herstatt et al., 2004).

Reducing uncertainty

The most obvious posture is reducing uncertainty, where additional information is collected before a decision is made, or a decision is postponed until the additional information can be collected. Often, this additional information is simply not available and the uncertainty can only be reduced by extrapolating available information from the past and present. Also, assumption-based reasoning can be applied where gaps in the information required for decision-making are filled by making assumptions. However, experience is required to do this efficiently. A combination of the approaches can be found in mental simulation or scenario building, where possible future developments are imagined in a structured way (Herstatt et al., 2004; Lipshitz & Strauss, 1997; Sniazhko, 2019).

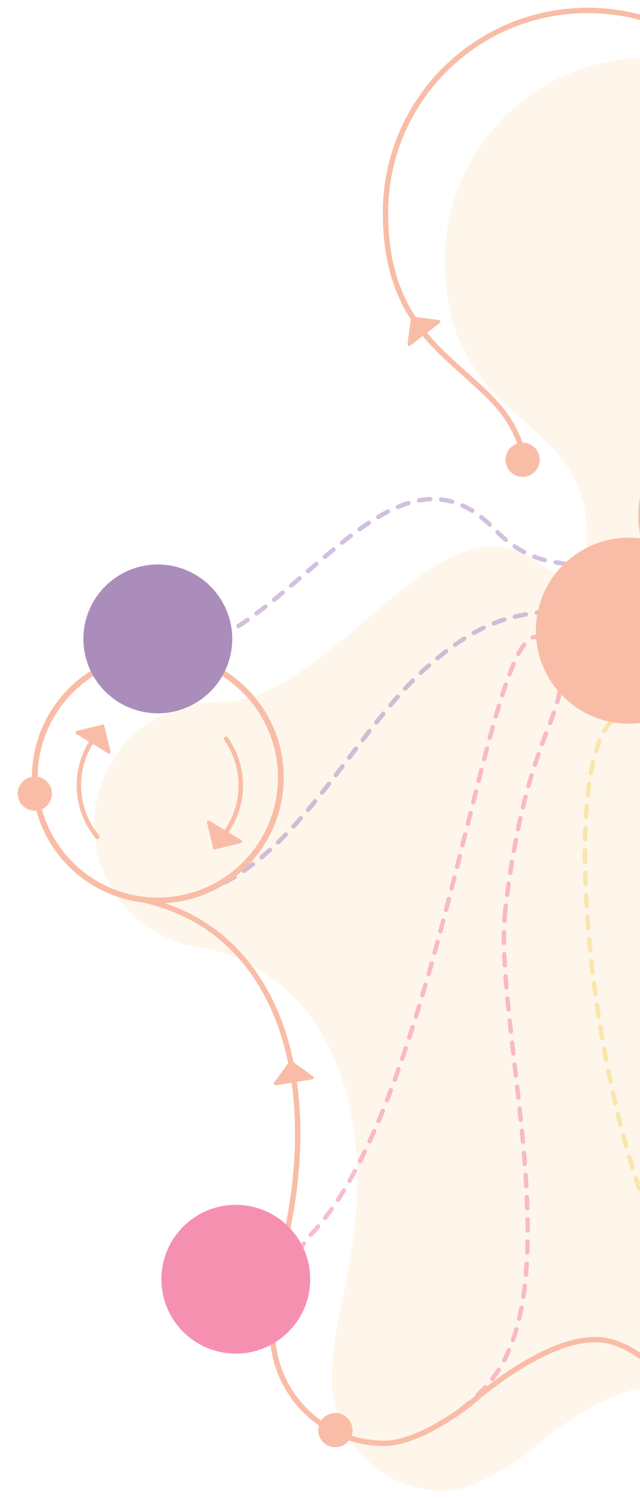
Acknowledging uncertainty

In many situations, uncertainty reduction is not feasible or too costly. The posture of acknowledging uncertainty provides an alternative, where decisions are made while taking into account potential uncertainties (or risks) and how these can be confronted or avoided. For example, organisations can build in buffers to protect themselves from temporary component shortages or can adopt a more flexible product development strategy that allows them to easily change the course of action when required. Also, a combination of assumption-based reasoning and preparing for uncertainties is possible (Jetter, 2003; Lipshitz & Strauss, 1997; Sniazhko, 2019).

Suppressing uncertainty

Finally, the posture of suppressing uncertainty can be recognised, where uncertainty is ignored or only symbolically addressed. For example, through denial or ignoring undesirable information. Often, a false sense of security is created through the believe that [a described outcome] will not happen (Lipshitz & Strauss, 1997).

When responding to uncertainty, it is essential to consider what posture fits the situation best. Questions to consider are: *'Do we need to reduce the uncertainty?', 'Can the uncertainty be reduced?'*, and *'Do we have the resources to reduce the uncertainty?'*. Moreover, avoiding the posture of suppressing uncertainty is critical at all times.



2. The Body Check Analysis

To gain more control over uncertainty in product development a method is required that aids the decision-making process to cope with uncertainty. The Body Check Analysis provides a structured method to identify uncertainties in the product development process, explore their potential impact, and define ways to deal with these. The Body Check Analysis, or BCA, is a stage-gate uncertainty analysis method for product development and innovation. The method guides designers and decision-makers in product development through the uncertainty analysis process. At the core of the analysis is the design brief that describes the goal of the analysis. Throughout the method, reflection gates can be found that help safeguard the quality of the analysis, and reflect upon the design brief to maintain focus in the analysis process (see Figures 2.1.A & 2.1.B).

2.1. Analogy

The Body Check Analysis represents an amorphous human figure that aims to adapt its lifestyle activities more specifically to what it requires or will require in the future (see Figure 2.1.A) to become stronger, healthier and happier. This is done by scanning its body and current lifestyle to determine its composition and personal needs. In product development and innovation, the 'body scan' will include a scan of the product design and its product development process. Aiming to decompose the uncertainties and challenges that are inherent to the design process, and find ways to adapt the decision-making process to deal with these uncertainties and challenges, now and in the time to come. The design brief forms the pumping heart of the analysis, and determines the pace, rhythm and depth in which the activities are executed. The different flows to and from the heart ensure all stages and gates are connected and aligned.

Whereas a medical examiner might ask you to take a closer look at your body and listen to what it needs, let's do the same for our designs!

Figure 2.1.A shows the structure of the method and how the different stages and gates are connected. This figure is especially useful when working with the reflection gates. It shows what parts of the method need to be included when performing this reflection and what parts of the method need to be reconsidered when a gate cannot be passed. In Figure 2.1.B, the process of the method is addressed in a storytelling approach. This overview helps to understand how the method is executed and what happens in each of the stages. This figure is most useful when explaining the method and highlighting the relevance of each of the stages towards the product development process.

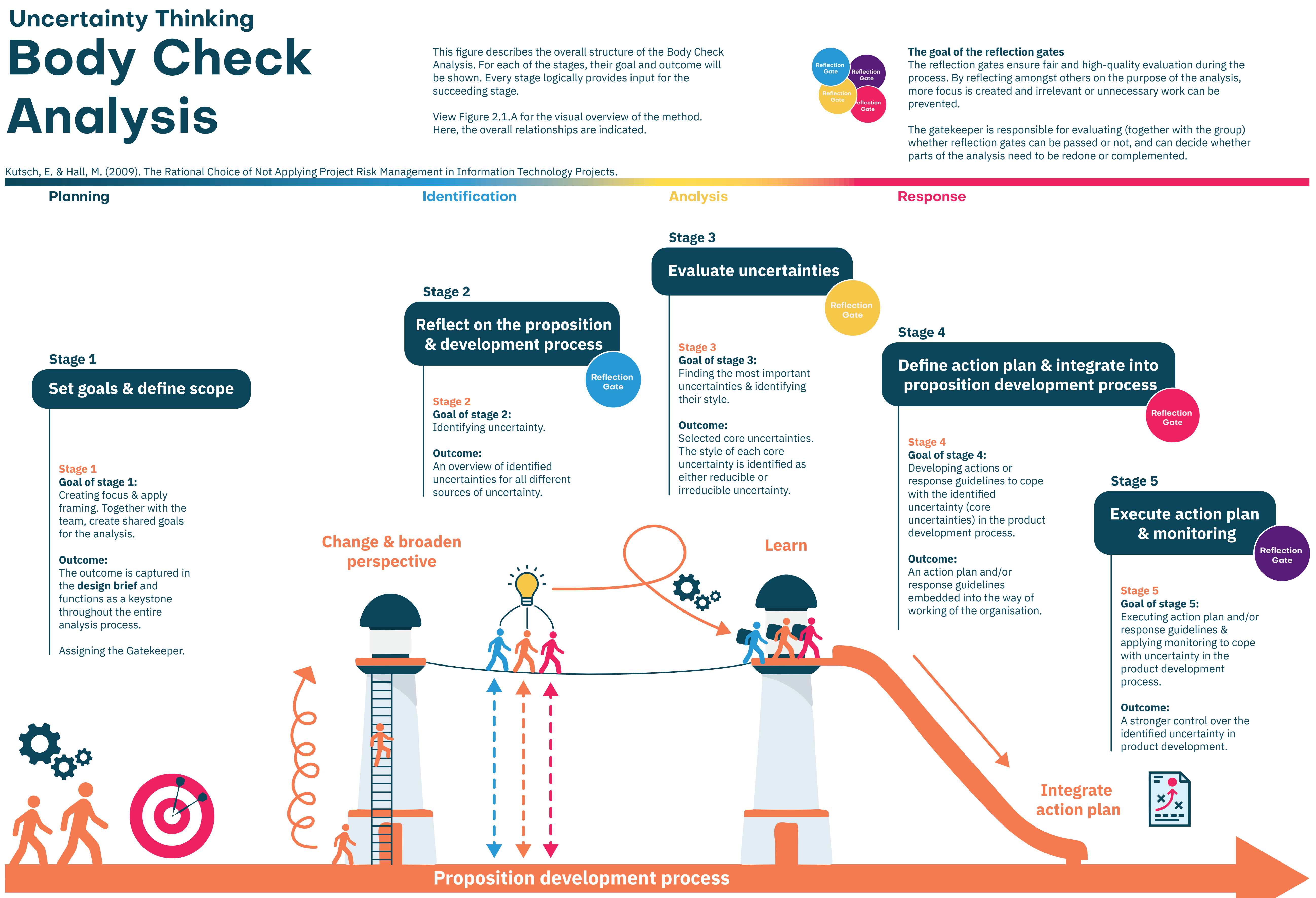


Figure 2.1.B - The Body Check Analysis. This figure describes the process of the Body Check Analysis. On the left, in stage 1, the goals for the analysis are formulated and captured in the design brief. Then, in stage 2, a high tower is climbed to reflect on the proposition development process with a diverse team with different expertise and insights from a new, broader and higher perspective. A spectrum of uncertainties is identified. In stage 3, the new knowledge is processed, and the identified uncertainties are evaluated for their impact and uncertainty to identify the most important - core - uncertainties. On the right side, in stage 4, the core uncertainties are transformed into an action plan and integrated into the proposition development process. In stage 5, the action plan is executed and monitored.

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Uncertainty Thinking
Body Check Analysis

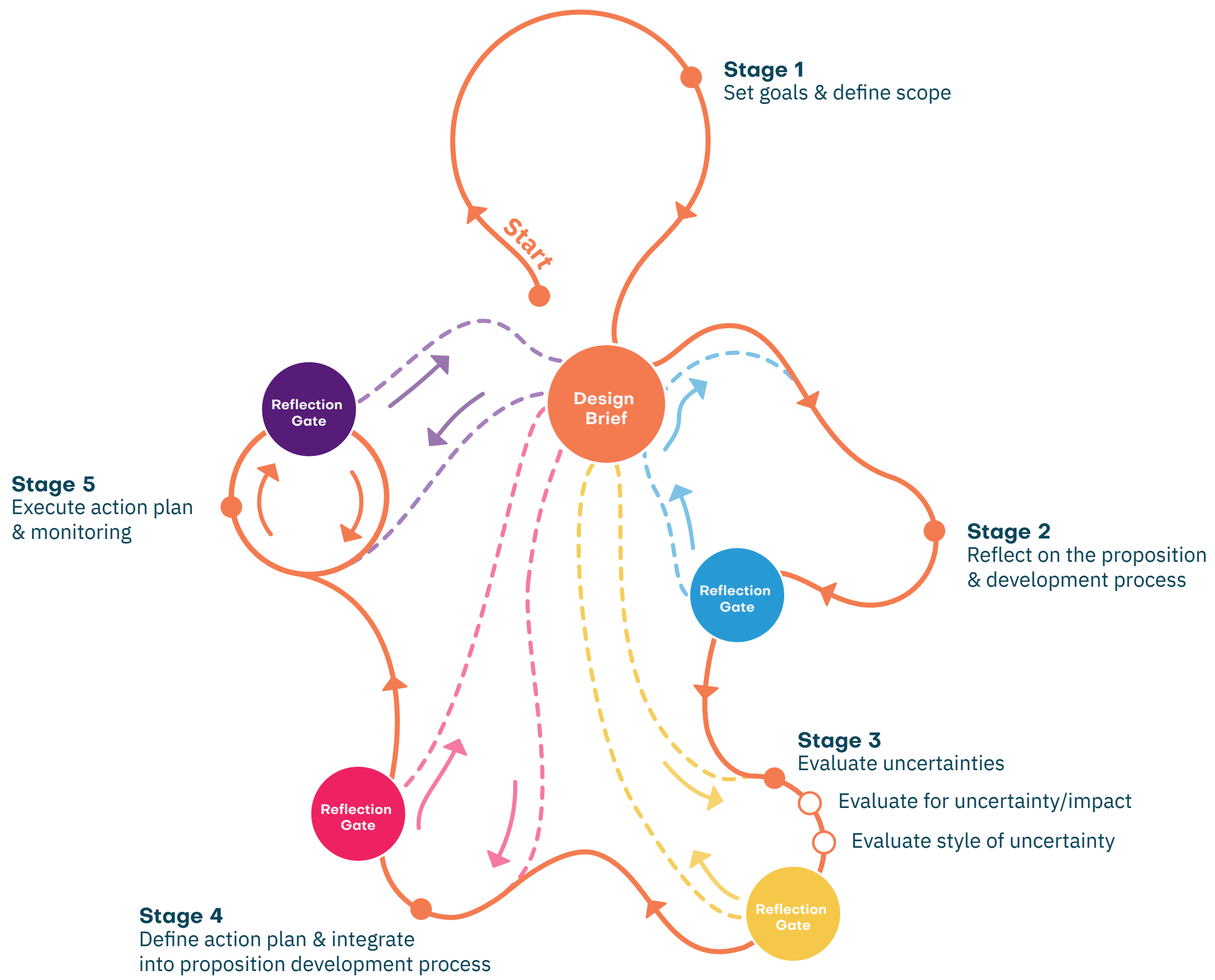

Figure 2.1.A - The Body Check Analysis. Visual & structural overview.

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2.2. Who should be part of the process?

The BCA can best be executed with the guidance of a designated facilitator who manages the process and supports group dynamics. This way, the group can fully focus on the analysis itself. The method is intended to be used in a group setting with participants from diverse backgrounds and expertise, apart from the members of the product development team itself. Inspired by the 'remarkable people' as discussed in the research of Bradfield et al. (2005), bringing in people with new knowledge will help to stimulate and challenge the thinking of the group to create a more comprehensive overview of identified uncertainties and create stronger response actions to the uncertainties. For example, when six people are part of the BCA team, two of those are part of the product development team itself of which at least one has a strong technical background, one from marketing, one from sales, one from product management (also gatekeeper), and one from operations.

The value of performing team-based uncertainty analysis transcends the mere deliverables it provides. The mental exercises support team building and create a learning process. It normalizes admitting "we do not know", and pushes the organisation to become a learning organisation for innovation management (Millett, 2003; Rice et al., 2008). Hence, the importance of the BCA lies not only in the results it generates but also in the process and way of thinking it engages within the organisation.

The role of the gatekeeper

To ensure fair and high-quality evaluation during the process, a gatekeeper needs to be assigned. The gatekeeper is responsible for evaluating (together with the group) whether reflection gates can be passed or not, and can decide whether parts of the analysis need to be redone or complemented. To do this, it is important the gatekeeper can bring an independent perspective into the analysis process. Hence, the gatekeeper cannot be part of the product development team itself and should be able to place the product development process and uncertainty analysis in a broader perspective. For example someone in product management from a different department within the organisation.

The role of the gatekeeper is an addition to the stage-gate approach of the BCA itself. This approach helps to assess the quality of execution of the method and understand whether the uncertainty analysis is on the right track. Moreover, it helps to maintain focus throughout the process by continuously reflecting on the objectives set in the design brief. The gatekeeper should safeguard this approach.

2.3. When to use the method?

In ideal NPD the level of uncertainty is gradually reduced throughout the development process (through decision-making) to a minimum when the product is launched. However, in reality, environmental developments and changes constantly create new uncertainties throughout not only the entire development process but also the entire life cycle of the product, see Figure 2.3.A (Jetter, 2003). Within the product development process, the fuzzy front end of product development tends to hold the highest degree of uncertainty, see Figure 2.3.A (Herstatt et al., 2004; Jetter, 2003). During this part of the

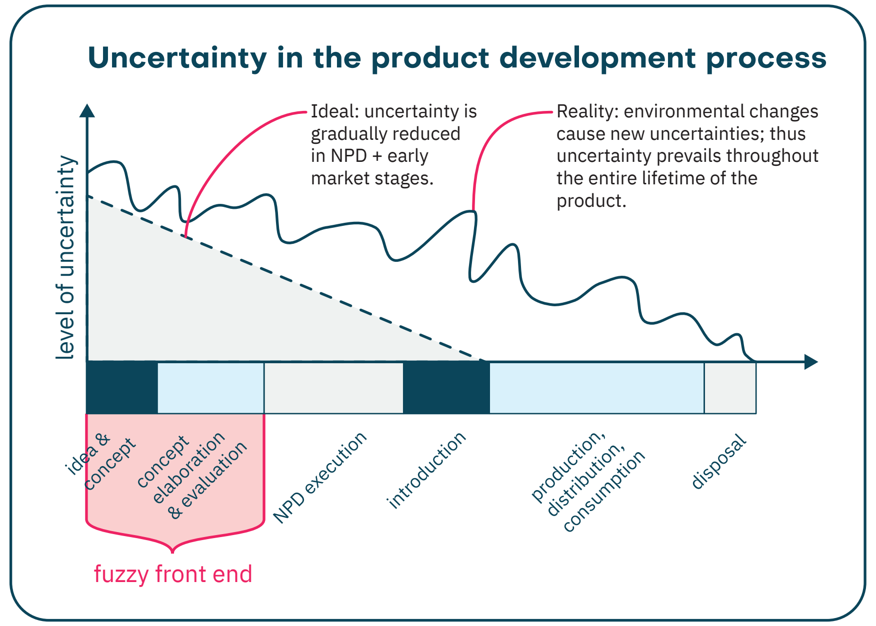


Figure 2.3.A - Uncertainty in the product development process. Adapted from Jetter, 2003.

development process not only is largely determined which development projects will be executed, but also the costs, quality and time frame are defined to a great extent. As such, the fuzzy front end bridges the gap between strategic activities (i.e. product portfolio planning and generating product ideas based on environmental scanning) and specifying product development tasks (Jetter, 2003). The research by Herstatt et al. (2004), also identified the fuzzy front end as the greatest weakness in product development.

When interviewing industry experts at a technology development company about the evolution of uncertainty throughout the product development process, similar findings could be recognised. The highest degree of uncertainty can be found in the fuzzy front end of the process. However, also later in the development process new uncertainties can be found due to environmental changes or decisions that have been made. The fuzzy front end was also identified to hold the most significant impact on the future success of the product (Goudsblom, 2022).

Based on the characteristics of the product development process, the Body Check Analysis can best be used in the following use cases:

- **Use case 1 - Workflow-based use case**: During the fuzzy front end of product development (i.e. at the end of the 'exploration' stage or the start of the 'create' stage in proposition development at Nedap) the method is used as a reflection tool to support decision-making regarding the focus of the development activities and deliver input. Here, the use case is embedded into the organisational planning and working cycle.
- **Use case 2 - Action-based use case**: Before large investments or decisions are made, the method is used to support decision-making. For example, deciding to take over another company to foster product development or the acquisition of specific technology.
- **Use case 3 - Problem-based use case**: When uncertainty-related difficulties are experienced in the development, or the development team gets stuck, the method is used to analyse the problems and find a solution direction or select development activities. For example, the envisioned product concept or solution seems unfeasible.

3. How to use the method?

This chapter will go more into detail about how the method can be executed. Each of the stages shall be discussed in more depth. In addition, an example will be shown on how the method can be executed. In the example, the fictive company Bliss Bike Manufacturing is conducting the BCA to investigate how it can become a market leader in developing bicycles for the shared mobility industry. Bliss is currently in the exploration phase (i.e. fuzzy front end) of their product development process. For the execution of the BCA, it employs a team of in total six employees – two of which are part of the original product development team for shared bicycles, and four are from elsewhere within the organisation.

The method can best be executed in a workshop setting, where one or multiple stages of the method are completed per workshop. For stages 1 to 4, a template is provided that can be used to guide the process.

3.1. Preparations

Before executing the Body Check Analysis, it is important several preparations are made. This section will highlight the most important preparations:

Facilitator

- Make a plan for the BCA sessions: How much time to spend on each stage and activity? How long should each workshop take? When should the workshops take place?
- Prepare presentation: The presentation should introduce the BCA, explain why the BCA is executed, and how the BCA and the individual stages work.
- Send the guidebook and project description to all participants and request them to read these.
- Print the four templates and arrange materials, such as markers, post-its, paper, pens, etc.
- For Stage 2 specifically: Divide the 11 sources of uncertainty over the participants (according to their expertise) and request them to investigate one or several of these domains to update their knowledge and think about possible uncertainties within the respective sources.

Gatekeeper

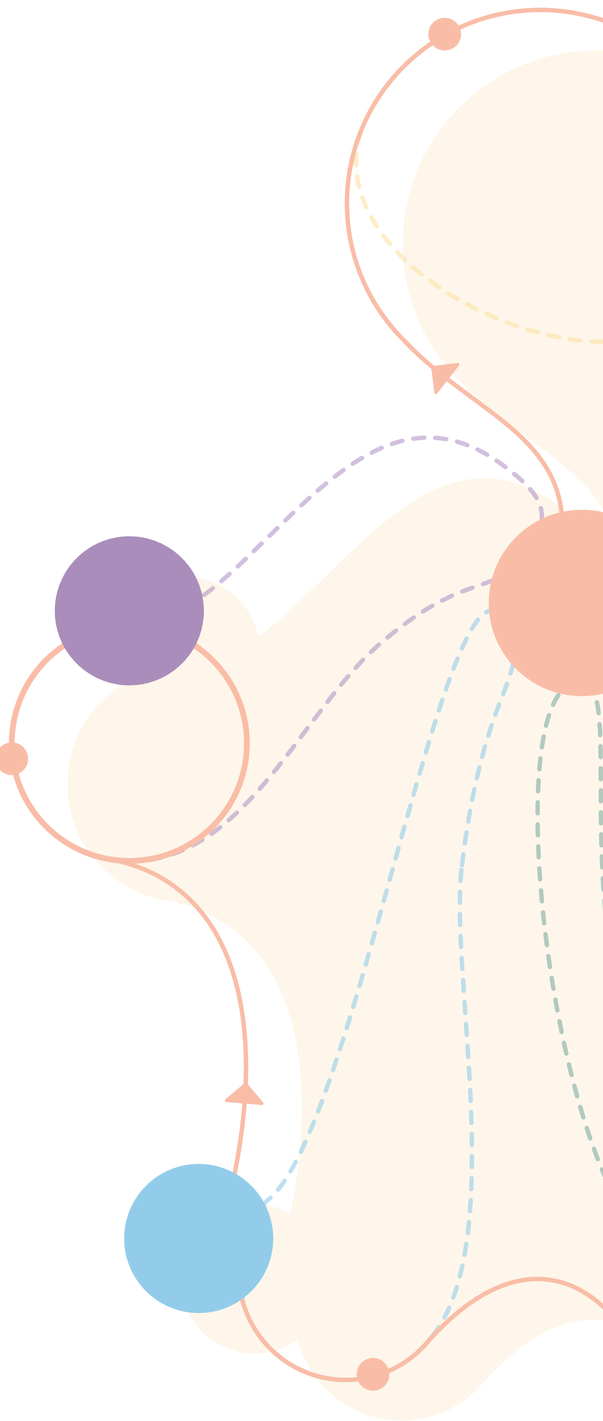
- Investigate the reflection gates and discuss the method with the facilitator.

Product development team

- Create a project description that provides a general introduction to the project, and highlights the latest developments and challenges that are being faced. The project description should be shared with the facilitator.

General participants

- Study the guidebook and project description.
- For Stage 2: Investigate the assigned sources of uncertainty.



Introducing the example case

Bliss Bike Manufacturing

All elements marked with this bar are part of the example case of Bliss Bike Manufacturing.

Introduction to the organisation: Bliss is a leading bike manufacturer with a strong brand identity centred around creating exceptional cycling experiences. With a deep passion for the freedom and joy that cycling brings, Bliss aims to inspire riders of all levels. The brand is renowned for its high-quality bikes that combine innovative design, cutting-edge technology, and superior performance. Bliss bikes are known for their style, durability, and exhilarating ride.

Brand Values: Bliss is guided by a set of core brand values that define its ethos and shape its offerings:

1. *Quality Craftsmanship*: Bliss takes pride in meticulous attention to detail and precision craftsmanship. Each bike is built with the highest quality components and materials, ensuring longevity and reliability.

2. *Innovation*: Bliss embraces innovation to push the boundaries of bike design and technology. The company incorporates advanced features and engineering techniques to enhance performance, comfort, and safety.

3. *Sustainability*: Bliss is committed to sustainable manufacturing practices. The brand strives to minimize its carbon footprint by using eco-friendly materials and promoting energy efficiency throughout its production processes.

4. *Customer Focus*: Bliss places great importance on customer satisfaction. The brand seeks to understand and cater to the unique needs and preferences of cyclists, providing exceptional customer service, personalized advice, and support for an unparalleled biking experience.

Design scope: As a leading bike manufacturer, our next logical step is to launch bicycles suitable for shared mobility. Leveraging our expertise in bike design and production, we can provide high-quality, well-maintained bicycles for short-term use. With the rising demand for eco-friendly transportation options, our bicycles designed for shared mobility could help businesses and public transportation companies offer cycling as a sustainable choice for urban commuting. Through a user-friendly mobile application, riders can easily locate and unlock our bikes, while incorporating innovative features like GPS tracking and electric assist capabilities. Expanding into shared mobility allows us to extend our brand reach and contribute to greener urban environments.

Stage 1 - Set goals & define scope

Goal: Creating focus & apply framing. Together with the team, create shared goals for the analysis. The output is captured in the design brief and functions as a keystone throughout the entire analysis process.

Outcome: Design brief. Clear focus and assignment for the analysis.

Explanation: The design brief is constructed of different topics that help create focus and apply framing to the uncertainty analysis process. For each of these different topics, several questions can be answered to help draft the design brief. These are viewed below. During the first stage the 'Gatekeeper' needs to be assigned.

Design brief formulation:
For creating the design brief, the following topics need to be considered:

Define the goal of the analysis
Here, the goal is to answer the question of why the analysis is needed. This is done by formulating goals:
'What goals do we have for the proposition itself?', and 'What goals do we have for the analysis?'

Describe the main actors and stakeholders
The stakeholder analysis describes the most relevant actors and stakeholders for the development of the proposition. They all have a relationship to the proposition and can influence the development process or success of the proposition, or be influenced by the proposition.

Define the main question and sub-questions
What is the main question that should be answered through the analysis? Often, the main question cannot be answered without first answering other questions. Hence, it is useful to formulate sub-questions.

Define the temporal and spatial scope of the analysis
Defining the temporal and spatial scopes will help to apply framing to the analysis.

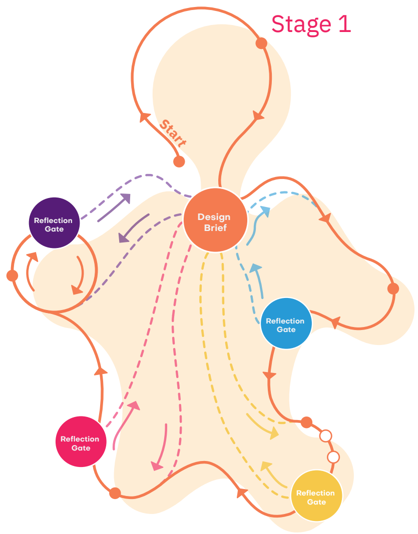
Describe the company's identity, core competencies and characteristics
When developing an action plan in stage 4 of the method, it is important the action plan fits well with the way of working of the organisation. Amongst other defining the risk tolerance or appetite will help identify what response actions fit well to the organisation.

Having a strong design brief will help to maintain focus throughout the analysis process. In each of the reflection gates, the design brief will be used to assess the progress of the analysis and evaluate whether it still matches the goals set. The **goal of the analysis** is most important for this.

Next to this, the **stakeholder analysis** supports the uncertainty identification that will be executed in stage 2 by investigating all the actors related to the development of the proposition.

The **temporal and spatial scope** will help evaluate the uncertainties in stage 3 by identifying what uncertainties are relevant to the scope of the proposition, and which are not or less relevant.

The **risk tolerance** will be used in stage 4 to create an action plan that fits well with the identity and risk appetite of the organisation.



Example of Design Brief

Purpose of the analysis:
Goal of the analysis: Investigating how to become a market leader in developing bicycles for shared mobility.

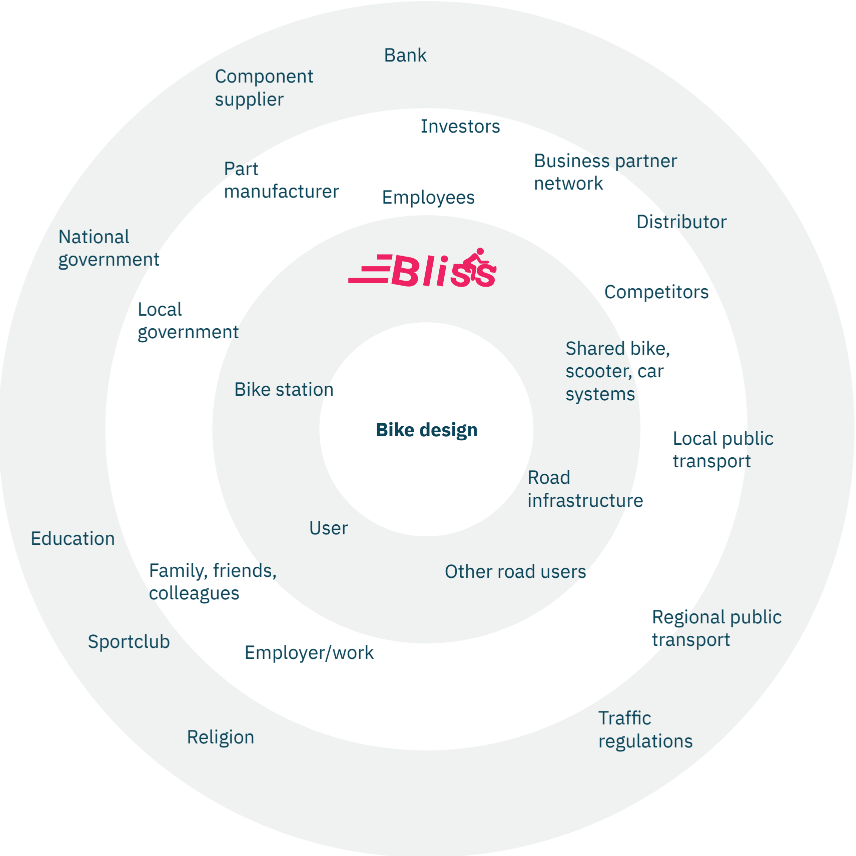
Main question: How do we ensure Bliss obtains a leading market position in developing bikes for shared mobility services?

Sub-question:
1. What business model is most suited?
2. Who are or could become our main competitors?
3. What partners should we align with?
4. What technologies are most fitting to use in our design?

Temporal scope: 10 years. For the development of the bicycles around 2 years is expected. However, more time will be needed to become the market leader. 10 years seem a more logical scope to make significant developments for this ambition.

Spatial scope: For the spatial scope, regions that have the following characteristics, or where these characteristics are developing, are mainly considered: strong cycling culture, well-developed cycling infrastructure, supportive policies, high population density, and a progressive environmental mindset. Here, we aim to focus on urban areas within Europe.

Main actors & stakeholders:



Core Competencies:
1. *Product Design and Innovation*: Bliss excels in product design, leveraging innovation to create bikes that embody exceptional craftsmanship, performance, and style. Their expertise in incorporating advanced technologies and materials sets them apart in the industry.

2. *Quality Craftsmanship*: Bliss is known for its commitment to quality craftsmanship, ensuring that their bikes meet high standards of durability, reliability, and performance. This core competence underscores their focus on providing customers with exceptional riding experiences.

3. *Sustainability and Environmental Awareness*: Bliss has a strong commitment to sustainability, as evidenced by their emphasis on eco-friendly materials, production processes, and the introduction of electric bikes. Their understanding of sustainability practices and environmental awareness is a key competence that resonates with their target audience.

Risk Appetite:
1. *Technological Advancements*: Bliss exhibits a willingness to embrace and invest in technological advancements. They are open to adopting new technologies and incorporating them into their product offerings, even if there are associated risks or uncertainties in terms of market reception or implementation challenges.

2. *Market Expansion*: Bliss demonstrates a moderate risk appetite for market expansion. The company has expanded its product range over the years, introducing different bike categories and venturing into electric bikes. This indicates a willingness to explore new markets and customer segments, albeit with a careful and strategic approach.

3. *Brand Reputation*: Bliss has established a strong brand reputation built on quality, craftsmanship, and innovation. This reputation suggests a risk-averse approach to protecting and maintaining their brand image. They are likely to prioritize maintaining customer trust and upholding their brand values over taking excessive risks that could potentially compromise their reputation.

Overall, Bliss's core competencies lie in product design and innovation, quality craftsmanship, and sustainability. While they demonstrate a willingness to embrace technological advancements and explore new markets, they approach these endeavours with a calculated risk appetite, aiming to protect their brand reputation and ensure customer satisfaction.

Stage 2 - Reflect on the proposition & development process

Goal: Identifying uncertainty.

Outcome: An overview of identified uncertainties for all different sources of uncertainty.

Explanation: In this stage, the proposition and its development process are reflected upon from a broad perspective by identifying uncertainties. To do this, the wheel of uncertainty is used. The wheel of uncertainty (see figure on the right) provides 11 different sources of uncertainty that can be experienced in the product development process.

Each source of uncertainty should be examined to obtain a broad overview of uncertainties related to the proposition. Strive to formulate a large and diverse set of uncertainties for each source.

A general description of each of these sources of uncertainties, including keywords and an example, is provide, see Table 1.2.1.A.

Recap uncertainty definition:
Uncertainty describes a deficiency between the amount and quality of information in possession, and the amount and quality of information required to make a decision or to perform a specific task. Moreover, it also describes the presence of unknown information that could have a strong impact on the future state of a product, system or strategy and its success.

How to formulate uncertainties?
Uncertainties can be formulated in multiple ways. Having clearly formulated uncertainties is helpful later in the process. The following guidelines can be used:

- *use clear language*; ensure other people can understand what you mean.
- *make them specific*; the more specific uncertainties are formulated, the more concrete they can be addressed later in the process.
- *one-at-a-time*; do not merge multiple uncertainties into one item, instead, formulate them seperately.

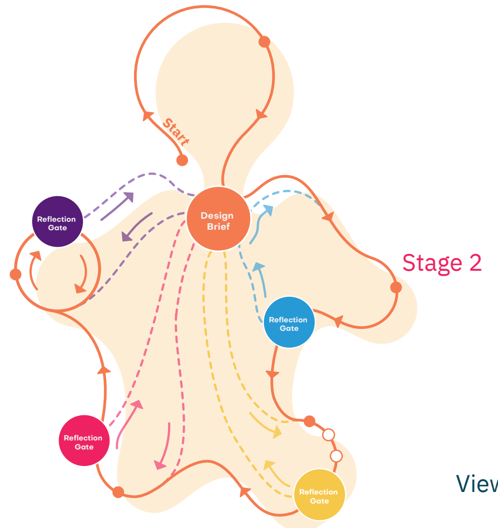
What format to use?
As long as the description fits the definition of uncertainty (as presented in the Guidebook, or below) it is good! This can be:

- A statement (e.g. scarcity of qualified labour).
- A question (e.g. does the solution fit into the current operating environment?).

Any format that expresses the uncertainty related to the proposition or experienced in the product development process should work. Aim to find a balance between the different formats available.

View Figure 3.2.A (open the fold-out page) for the example case.

This step will help to create a clear overview of all uncertainties relevant to the proposition and the product development process. In the following stages, the uncertainties will be evaluated to find the most important uncertainties and an action plan will be created on how to cope with these uncertainties.



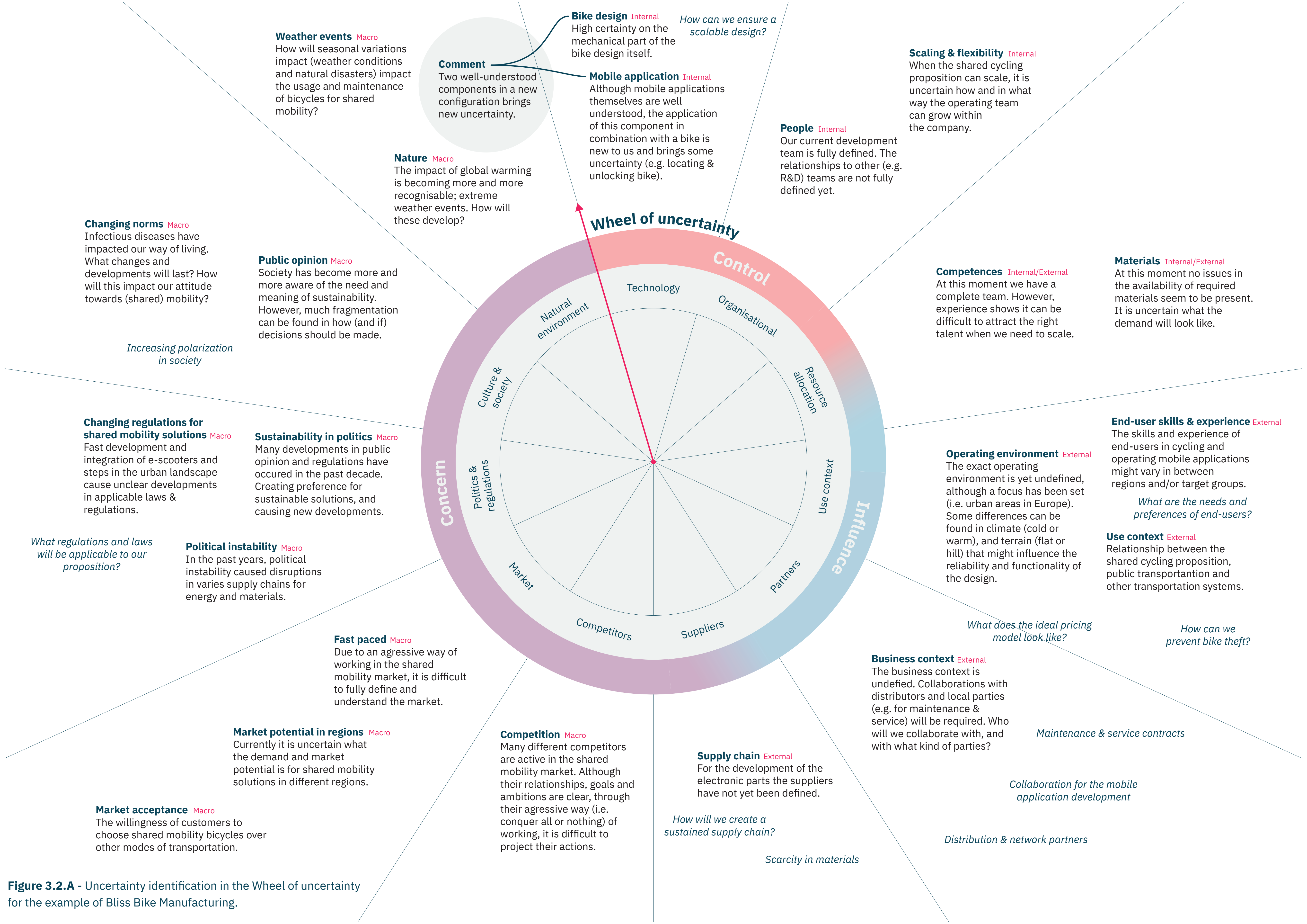


Figure 3.2.A - Uncertainty identification in the Wheel of uncertainty for the example of Bliss Bike Manufacturing.

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Stage 3 - Evaluate uncertainties

Goal: Finding the most important uncertainties & identifying their style.

Outcome: Selected core uncertainties. The style of each core uncertainty is identified as either reducible or irreducible uncertainty.

Explanation: This stage consists of two steps; 'evaluate for uncertainty/impact' and 'evaluate style of uncertainty'. After executing these two steps, the most important uncertainties (in relation to the main question in the design brief) have been selected (the core uncertainties) and the style of their uncertainty is identified that will help to create an action plan in the next stage.

This step will help to identify the most important uncertainties that need to be coped with to achieve the goals of the proposition and the analysis (as defined in the design brief). After completion of this step, a selection of core uncertainties is made.

1. Evaluate for uncertainty/impact

Each of the identified uncertainties from stage 2 need to be evaluated for their impact (related to the main question) and their uncertainty in relation to one another. Mind that uncertainty not only includes the probability of occurrence of a situation or condition but also how a situation or condition will develop over time.

Core uncertainties are often characterised by a high uncertainty and/or high impact in relation to the goal of the analysis (see Figure 3.3.A, open the fold-out page).

This step will help to identify how we can best cope with the core uncertainties. For reducible uncertainty, we can focus more on response actions to reduce the uncertainty. For irreducible uncertainty, first we should focus on monitoring to evaluate how the uncertainty is developing, and then on response actions.

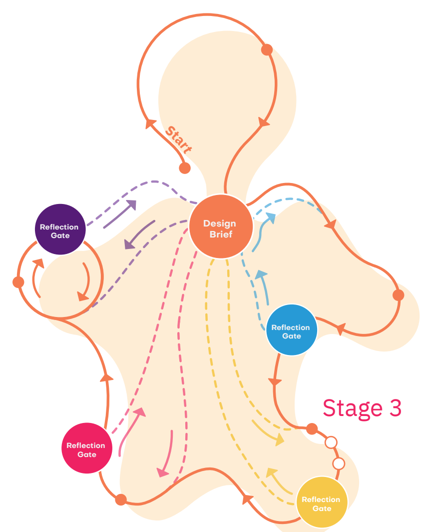
2. Evaluate the style of uncertainty

Defining the style of uncertainty allows us to more specifically assign response actions to the core uncertainties when creating the action plan. The style can be characterised by reducible or irreducible uncertainty (De Weck et al., 2007). For each identified core uncertainty needs to be indicated whether the uncertainty is reducible or irreducible.

Reducible uncertainty relates to a lack of definition or lack of knowledge, and with additional effort, this ambiguity or lack of knowledge can be reduced, as the issues are relatively well understood. Examples are the reliability of technical components, or corporate strategy and commitment (De Weck et al., 2007). From an organisational perspective, this means the uncertainty can be influenced by the organisation. When developing an action plan, more focus will be on creating response actions and guidelines.

Irreducible uncertainty can only be 'explained' by the occurrence of future events. Examples are the results of a sports match, or the value of a portfolio on the stock market in a year (De Weck et al., 2007). From an organisational perspective, this means the uncertainty cannot be influenced by the organisation. When developing an action plan, more focus will be on monitoring.

View Figure 3.3.B (open the fold-out page) for the example case.



Reflection gate

Reflection gate

When reflecting on the wheel of uncertainty in stage 2, the gatekeeper together with the team concludes that the overview of identified gives a fair and complete representation of the project. Moreover, the identified uncertainties are well formulated (i.e. use clear language, make them specific, and one-at-a-time).

To evaluate this, the gatekeeper asked colleagues outside the BCA team to review the wheel of uncertainty. These colleagues were given a briefing on the project itself and the BCA. Some colleagues were invited because of their expertise (e.g. legislation, marketing, engineering, sales, sustainability, etc.). They were asked to evaluate the completeness of the wheel of uncertainty, while specifically focussing on their domain of expertise. Other colleagues were asked to focus more on the understandability of the formulated uncertainties.

'Do the identified uncertainties give a fair and complete representation of the project?'

- Are the uncertainties well formulated? Check the guidelines provides in the Body Check Analysis guidebook.

open

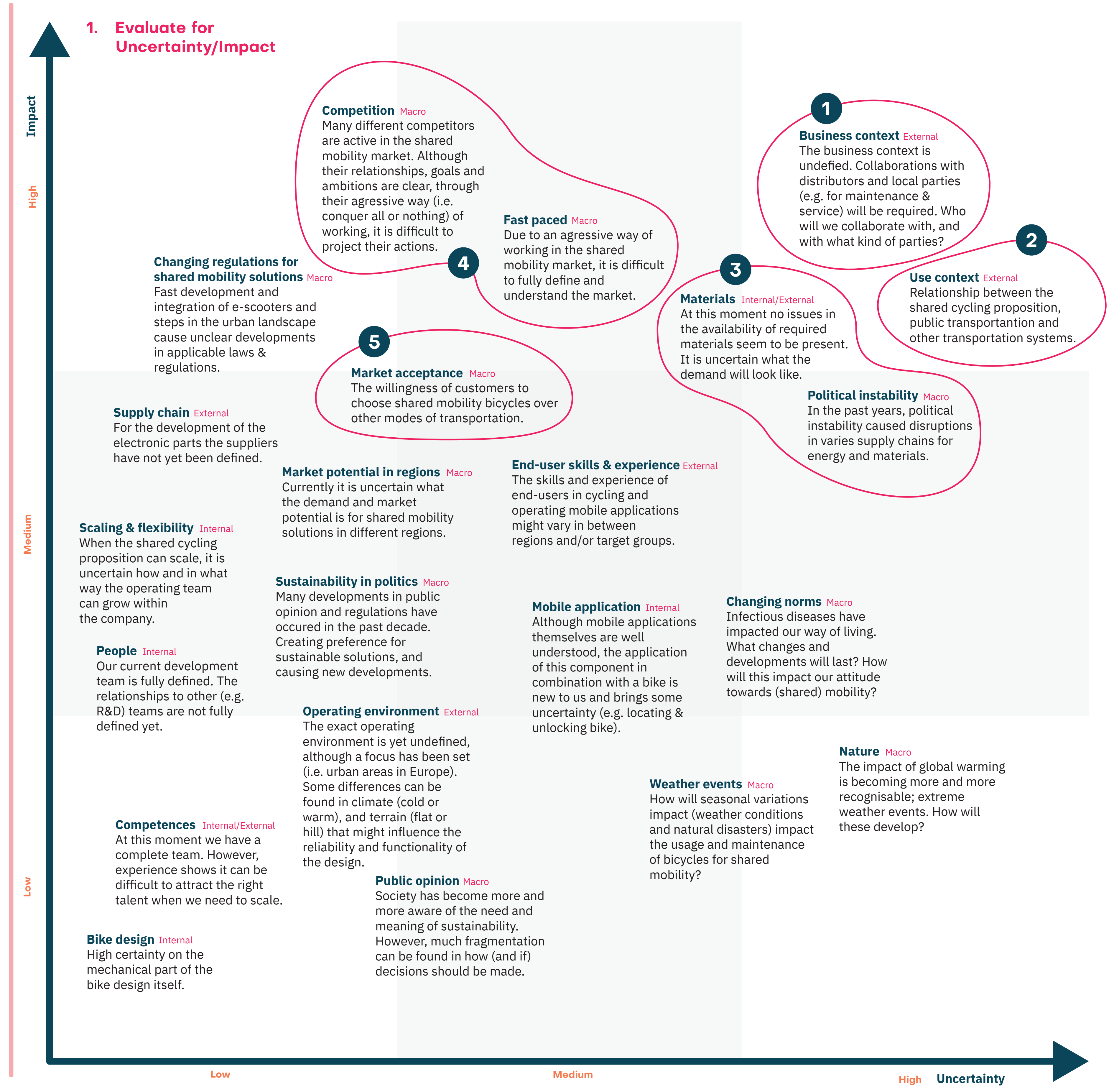


Figure 3.3.A - Evaluation of all uncertainties for their respective uncertainty and impact or the example of Bliss Bike Manufacturing. The core uncertainties have been marked with numbers.

2. Evaluate the style of uncertainty

	Core uncertainties	Style of uncertainty
1	New business partnerships and collaborations	Reducible
2	Use context and location	Reducible
3	Increasing scarcity in materials	Irreducible
4	Agressive way of working in the shared mobility market	Reducible
5	Transition from ownership to use	Reducible

Figure 3.3.B - Evaluation of all uncertainties for their style or the example of Bliss Bike Manufacturing. Each of the core uncertainties is categorized as either reducible or irreducible.

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Reflection gate

'Do the identified core uncertainties address the goal of the uncertainty analysis as defined in the design brief?'

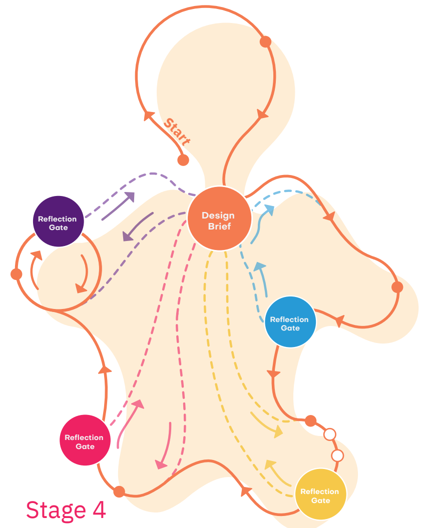
Reflection gate

When reflecting on the created work in stage 3, the gatekeeper together with the team concludes that the defined core uncertainties address the goal of the analysis well. The core uncertainties are very relevant in obtaining a leading market position.

When reflecting on the uncertainty/impact matrix, the core uncertainties also capture the uncertainties that ranked highest on both the impact and uncertainty scales well. However, they do realize the uncertainty of 'changing regulations for shared mobility solutions' ranks very high on the impact scale and is not included in the core uncertainty due to its low uncertainty. They decide to ask the legal department to investigate this uncertainty in the coming design sprint and report back. Depending on the outcome of their investigation, they can decide whether this uncertainty should still be included in the core uncertainties or not.

Response action
When this (i.e. change or development) happens, this is ***what*** we are going to do next.

Response guideline
When this (i.e. change or development) happens, this is ***how*** we are going to do things next.



Stage 4

Stage 4 - Define action plan & integrate into proposition development process

Goal: Developing actions or response guidelines to cope with the identified uncertainties (core uncertainties) in the product development process.

Outcome: An action plan and/or response guidelines embedded into the way of working of the organisation.

Explanation: In this stage, actions are defined that can actively be undertaken to minimize the negative impact of the identified uncertainties. These actions are captured in the action plan and are based on the core uncertainties.

Next, this action plan is embedded into the way of working of the organisation to ensure continuity and execution of the plan.

1. Creating the action plan
The action plan consists of two elements; monitoring and response actions or guidelines.

Monitoring focuses on identifying change or developments in the core uncertainty. It helps to identify whether the project is on the right track and how we should respond to the core uncertainty. Monitoring can both be activities that are actively executed (e.g. examine stakeholders preferences, investigate specific markets) or events or developments that can happen (e.g. development of new technology, launch of competitor's product, changing regulations).

Response actions or guidelines focus on how to respond to these changes and developments that can be observed through monitoring (e.g. engage field test, expand/reduce project team, train personnel at business partner, publically present project).

View Figure 3.4.A for the example case.

2. Embedding action plan into the way of working
Embed the action plan into the way of working of the organisation to ensure continuity and execution of the plan. This is done by making an agreement with the team.

Topics to think about:
- *Responsibility*: Who is/are responsible for the execution of the plan?
- *Reviewing the action plan*: When and how often should the action plan be reviewed (to execute the monitoring)?
- *Decision-making*: Who needs to be involved when decisions have to be made?
- *Validity of the action plan*: How do we determine the validity of the action plan? Or when should a new Body Check Analysis be executed?

open

Core uncertainty Reducible

This core uncertainty is **reducible**. Hence, Bliss can actively put in extra effort to become more certain. Monitoring will not only help to understand the uncertainty better but also to reduce the uncertainty.

1 New business partnerships and collaborations

Monitoring

Conduct market intelligence.

Approach potential business partners and interview.

Response action or guideline

action: Decide on business context.

guideline: **Working with business partners**
Involve business partners in development process.

action: Develop system for payments and product use through business partners.

Core uncertainty Reducible

This core uncertainty is **reducible**. Hence, Bliss can actively put in extra effort to become more certain. Monitoring will not only help to understand the uncertainty better but also to reduce the uncertainty.

2 Use context and location

Monitoring

Hire market research agency to investigate.

Social listening (marketing).

Interview potential users.

Response action or guideline

action: Decide on use context; 'extension of public transport' vs 'local transportantion network'.

Core uncertainty Irreducible

This core uncertainty is **irreducible**. Hence, putting in extra effort to reduce the uncertainty is not possible. Bliss focusses on actively monitoring changes and developments.

3 Increasing scarcity in materials

Monitoring

Track the availability of components and map delivery issues and causes.

Stay up-to-date on international (political) developments.

Response action or guideline

guideline: **Material scarcity**
Designing out complexity. Create modular constructed product and reduce number of critical components.

action: **Material scarcity**
Work with more suppliers to build a broader and more stable supply network.

Core uncertainty Reducible

This core uncertainty is **reducible**. Hence, Bliss can actively put in extra effort to become more certain. Monitoring will not only help to understand the uncertainty better but also to reduce the uncertainty.

4 Agressive way of working in the shared mobility market

Monitoring

Study competitors. Check their speed and stability.

Social listening (marketing).

Check investment decks.

Response action or guideline

action: Inform partners about the product in development.

action: Re-evaluate chance of succes.

Core uncertainty Reducible

This core uncertainty is **reducible**. Hence, Bliss can actively put in extra effort to become more certain. Monitoring will not only help to understand the uncertainty better but also to reduce the uncertainty.

5 Transition from ownership to use

Monitoring

Conduct market survey to understand consumer values.

Social listening (marketing).

Response action or guideline

Transition to use
action: Perform co-design session with potential end user.

Transition to ownership
action: Re-evaluate chance of succes.

Figure 3.4.A - Action plan for the example of Bliss Bike Manufacturing. For each core uncertainty several monitoring activities are shown and response actions or guidelines.

Embedding the action plan into the way of working of the organisation

To safeguard the created work and knowledge, the team of Bliss embedded the early warning system in the following way into their organisation:

Responsibility: The product manager responsible for the shared cycling solution is charged with the responsibility for the execution of the action plan and monitoring. This does not imply the product manager should execute the action plan and the monitoring activities themselves, however, they should ensure that these are being executed. The product manager assigns the monitoring activities that need to be executed to the respective colleagues.

For example, the marketing department of Bliss Bike Manufacturing is requested to investigate 'market intelligence', 'social listening' and 'conducting market surveys'. The operations department is requested to 'keep track of the availability of components and map any delivery issues they are experiencing and the issues that cause these'.

Reviewing the action plan: The team decides the action plan and monitoring activities for the five core uncertainties should be checked quarterly and discussed every quartile review. Here, other product managers or the product management team can respond to the shared conclusions and can together decide whether the design strategy needs to adapt according to the action plan. Moreover, the validity of the action plan also needs to be evaluated here (see stage 5)

Decision-making: This depends on the decisions that need to be made. Generally speaking, the most important decision-makers are the product development team, the product manager and the product leadership team.

Validity of the action plan: The action plan is considered no longer valid when

- A core uncertainty is completely reduced or deemed no longer relevant. A critical uncertainty has been resolved and it is now time to focus on the other (slightly less significant) uncertainties and create an action plan for those. *Action*: Review the BCA and define a new core uncertainty or fully execute the BCA again.
- The project's chance of success is re-evaluated and receives a negative outcome.

Reflection gate

When reflecting on the created work in stage 4, the gatekeeper together with the team concludes that the action plan matches the goal of the analysis as defined in the design brief well. The action plan addresses the main question that concerns how to obtain a leading market position, and most of the sub-questions. Only sub-question four about 'technology' is not well reflected in the action plan. As none of the core uncertainties addresses this topic (i.e. none of the uncertainties that ranked high on impact and uncertainty concerned 'technology'), they deem the current action plan good. The monitoring activities help decide when and if the defined response actions and guidelines should be executed. Moreover, the action plan and monitoring are well embedded into the way of working.

Reflection gate

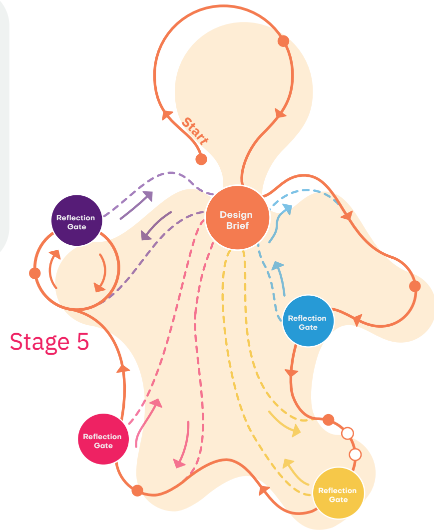
'Do the defined response actions or guidelines (the action plan) match the goal of the analysis as described in the design brief?'

- Do the defined response actions match the monitoring approach?
- Can the defined response actions and monitoring be executed as part of the way of working of the organisation?

Stage 5 - Execute action plan & monitoring

Goal: Executing action plan and/or response guidelines & applying monitoring to cope with uncertainty in the product development process.

Outcome: A stronger control over the identified uncertainty in product development.



Explanation: By creating an action plan, concrete approaches have been installed to deal with the uncertainty identified in the product development process. However, merely having this plan will not yet result any improvements. Therefore it is important the action plan and monitoring activities are executed and safeguarded in the organisation's way of working (see Figure 3.5.A).

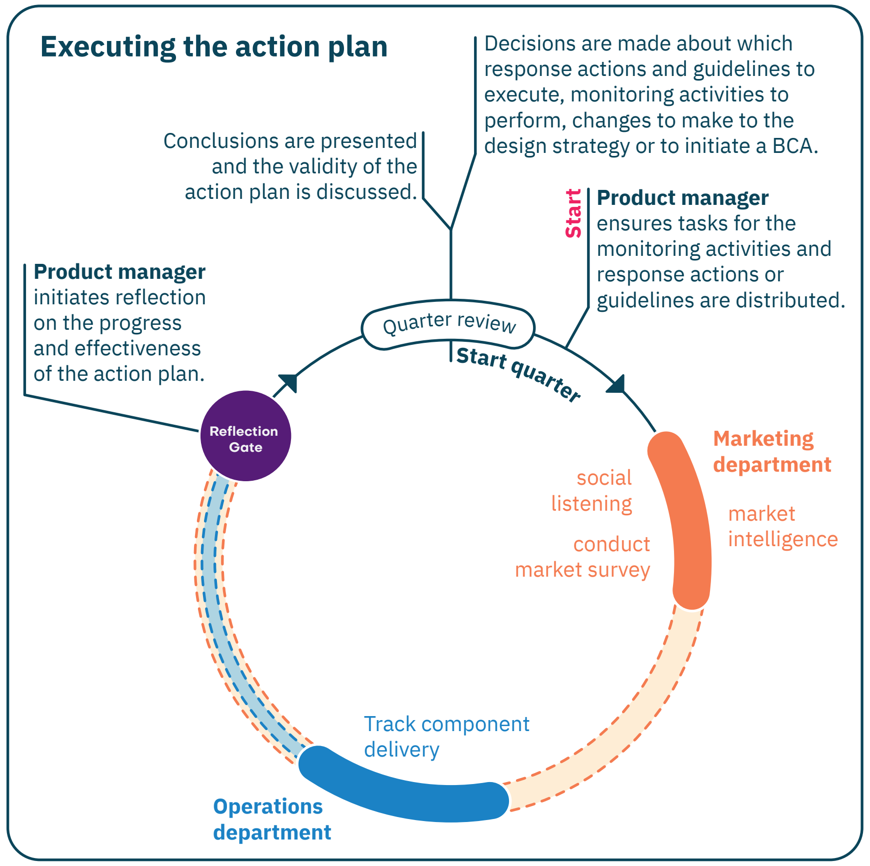


Figure 3.5.A - Execution of the action plan in one quarter for the example of Bliss Bike Manufacturing.

Reflection gate

This is the first reflection gate that is executed outside of the workshop setting where stages 1 to 4 were executed. Hence, in the case of Bliss Bike Manufacturing, the product manager is responsible for initiating the reflection gate. They chose to do this within the project development team and invited one other colleague from outside their team who was also part of the BCA. When reflecting on the executed monitoring activities in stage 5, the team concludes at the quarter review that the marketing research activities do not yield the required knowledge to make decisions and activate any of the response actions. Hence, they decided to hire a market research agency. At this moment the response actions and monitoring approach are still considered valid and the BCA should not yet be redone.

Reflection gate

'Did the response actions have the intended effect and addressed the initial goal of the analysis as described in the design brief?'

- How effective are the response actions?
  - Are the response actions and monitoring approach still valid, considering changing conditions?
  - Should (a part) of the uncertainty analysis be redone?

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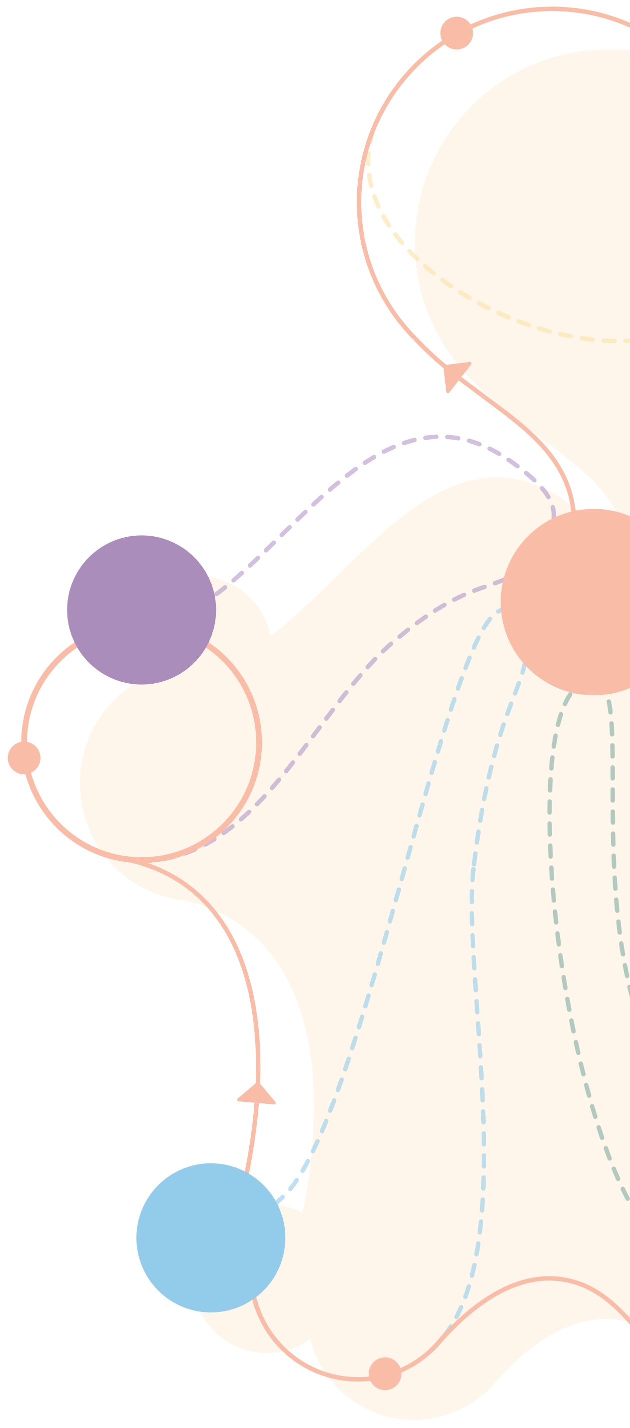

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View page 18-21 of the Guidebook

Stage 1

Uncertainty Thinking
Body Check Analysis

Stage 1
Set goals & define scope

Goal: Creating focus & applying framing. Together with the team, create shared goals for the analysis.

Outcome: The outcome is captured in the **design brief** and functions as a keystone throughout the entire analysis process.

Assigning the Gatekeeper.

Explanation: The design brief is constructed of different topics that help create focus and apply framing to the uncertainty analysis process. For each of these different topics, several questions can be answered to help draft the design brief. These are viewed below. During the first stage the 'Gatekeeper' needs to be assigned.

Design brief formulation: For creating the design brief, the following topics need to be considered:

1. ***Define the goal of the analysis***
Here, the goal is to answer the question of why the analysis is needed. This is done by formulating goals:
'What goals do we have for the proposition itself?', and *'What goals do we have for the analysis?'*

2. ***Describe the main actors and stakeholders***
The stakeholder analysis describes the most relevant actors and stakeholders for the development of the proposition. They all have a relationship to the proposition and can influence the development process or success of the proposition, or be influenced by the proposition.

3. ***Define the main question and sub-questions***
What is the main question that should be answered through the analysis? Often, the main question cannot be answered without first answering other questions. Hence, it is useful to formulate sub-questions.

4. ***Define the temporal and spatial scope of the analysis***
Defining the temporal and spatial scopes will help to apply framing to the analysis.

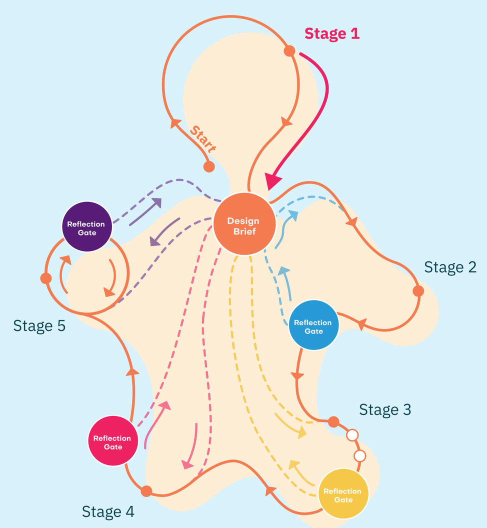
5. ***Describe the company's identity, core competencies and characteristics***
When developing an action plan in stage 4 of the method, it is important the action plan fits well with the way of working of the organisation. Amongst other defining the risk tolerance or appetite will help identify what response actions fit well to the organisation.

Having a strong design brief will help to maintain focus throughout the analysis process. In each of the *reflection gates*, the design brief will be used to assess the progress of the analysis and evaluate whether it still matches the goals set. The goal of the analysis most important for this.

Next to this, the stakeholder analysis supports the uncertainty identification that will be executed in *stage 2* by investigating all the actors related to the development of the proposition.

The temporal and spatial scope will help evaluate the uncertainties in *stage 3* by identifying what uncertainties are relevant to the scope of the proposition, and which are not or less relevant.

The risk tolerance will be used in *stage 4* to create an action plan that fits well with the identity and risk appetite of the organisation.



1. Define the goal of the analysis

What goals do we have for the proposition?
What goals do we have for the analysis?

4. Define the temporal and spatial scope

Apply framing to the analysis by defining the temporal and spatial scope.
Temporal = time; what time frame to investigate
Spatial = geological; what part of the world to investigate

5. Describe the organisation

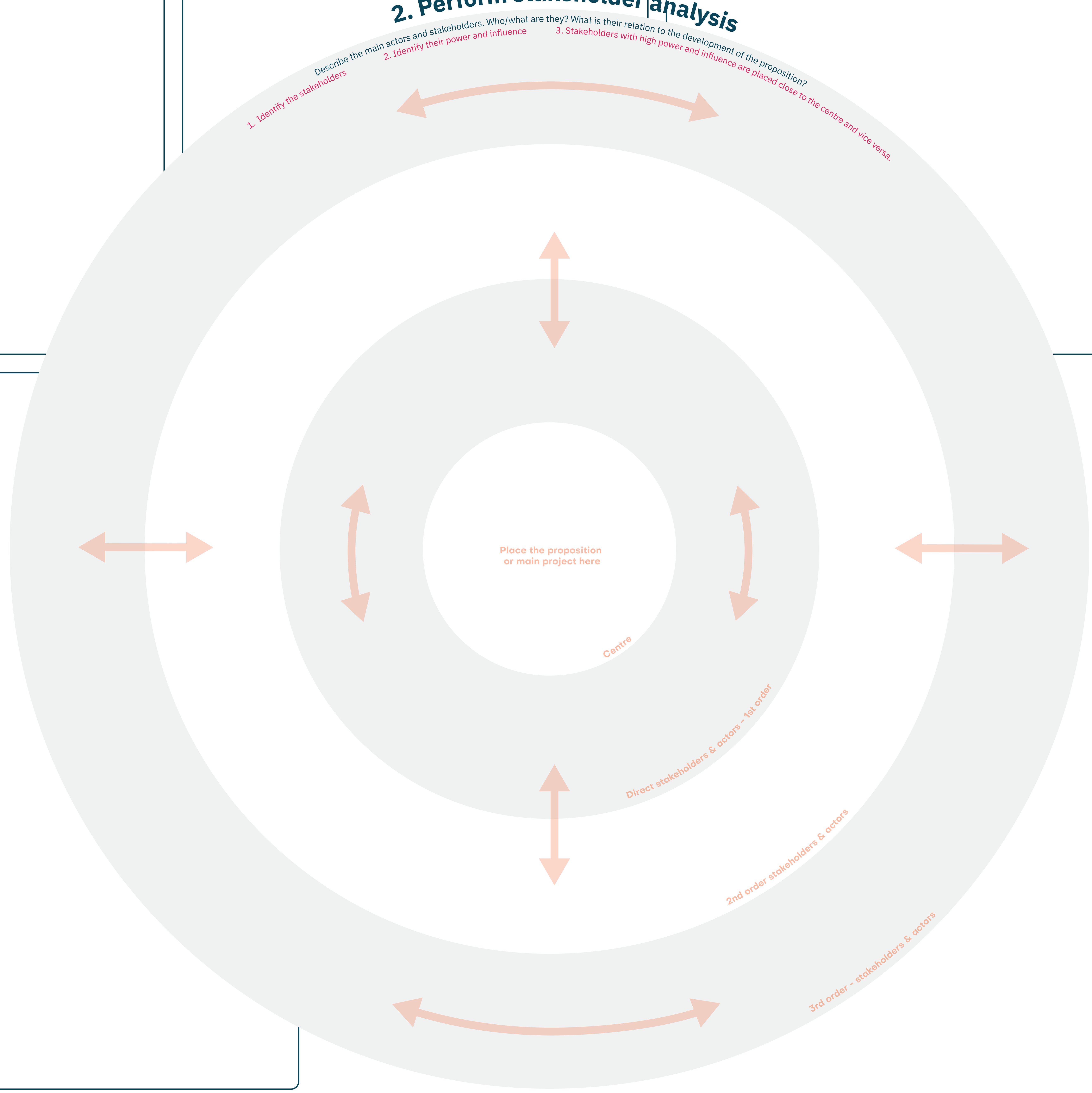
What is the identity of the organisation?
How can the risk-tolerance of the organisation be described?

Risk tolerance:

No risk — Maximum risk

0 1 2 3 4 5 6 7 8 9 10

2. Perform stakeholder analysis



3. Define the main question and sub-questions

View page **22-23** of the Guidebook

Stage 2

Uncertainty Thinking

Body Check Analysis

Stage 2
Reflect on the proposition & development process

Goal: Identifying uncertainty.

Outcome: An overview of identified uncertainties for all different sources of uncertainty.

Explanation: In this stage, the proposition and its development process are reflected upon from a broad perspective by identifying uncertainties. To do this, the wheel of uncertainty is used. The wheel of uncertainty (see figure on the right) provides 11 different sources of uncertainties that can be experienced in the product development process.

Each source of uncertainty should be examined to obtain a broad overview of uncertainties related to the proposition. Strive to formulate a large and diverse set of uncertainties for each source.

In the Guidebook of the Body Check Analysis a description, keywords and an example is provided for each source, see page 8-9 (including the fold-out pages). It is recommended to review these before starting the uncertainty identification. In the figure on the right, the keywords can also be found.

How to formulate uncertainties?
Uncertainties can be formulated in multiple ways. Having clearly formulated uncertainties is helpful later in the process. The following guidelines can be used:

- *use clear language*; ensure other people can understand what you mean.
- *make them specific*; the more specific uncertainties are formulated, the more concrete they can be addressed later in the process.
- *one-at-a-time*; do not merge multiple uncertainties into one item, instead, formulate them seperately.

What format to use?
As long as the description fits the definition of uncertainty (as presented in the Guidebook, or below) it is good! This can be:

- A statement (e.g. scarcity of qualified labour).
- A question (e.g. does the solution fit into the current operating environment?).

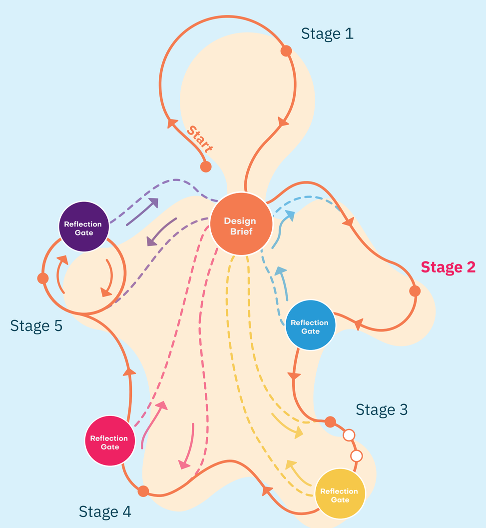
Any format that expresses the uncertainty related to the proposition or experienced in the product development process should work. Aim to find a balance between the different formats available.

This step will help to create a clear overview of all uncertainties relevant to the proposition and the product development process. In the following stages, the uncertainties will be evaluated to find the most important uncertainties and an action plan will be created on how to cope with these uncertainties.

Terminology - recap
Uncertainty: 'Uncertainty describes a deficiency between the amount and quality of information in possession, and the amount and quality of information required to make a decision or to perform a specific task. Moreover, it describes the presence of unknown information that could have a strong impact on the future state of a product, system or strategy and its success.'

Risk: Risk describes "an uncertain event or condition that, if it occurs, has a positive or negative effect on a project objective. A risk has a cause and, if it occurs, a consequence." (Project Management Institute, 2000, p. 127). For example, the cause may be labour shortage, the risk event is that there is no adequate labour for the task, and the consequence may be delayed project planning. The origin of risk can be found in the uncertainty that is present in all projects. (Project Management Institute, 2000; Ward & Chapman, 2003).

Impact: The impact describes a strong effect or influence that something has on someone, something or a situation (Cambridge Dictionary, 2023).



1. Uncertainty identification

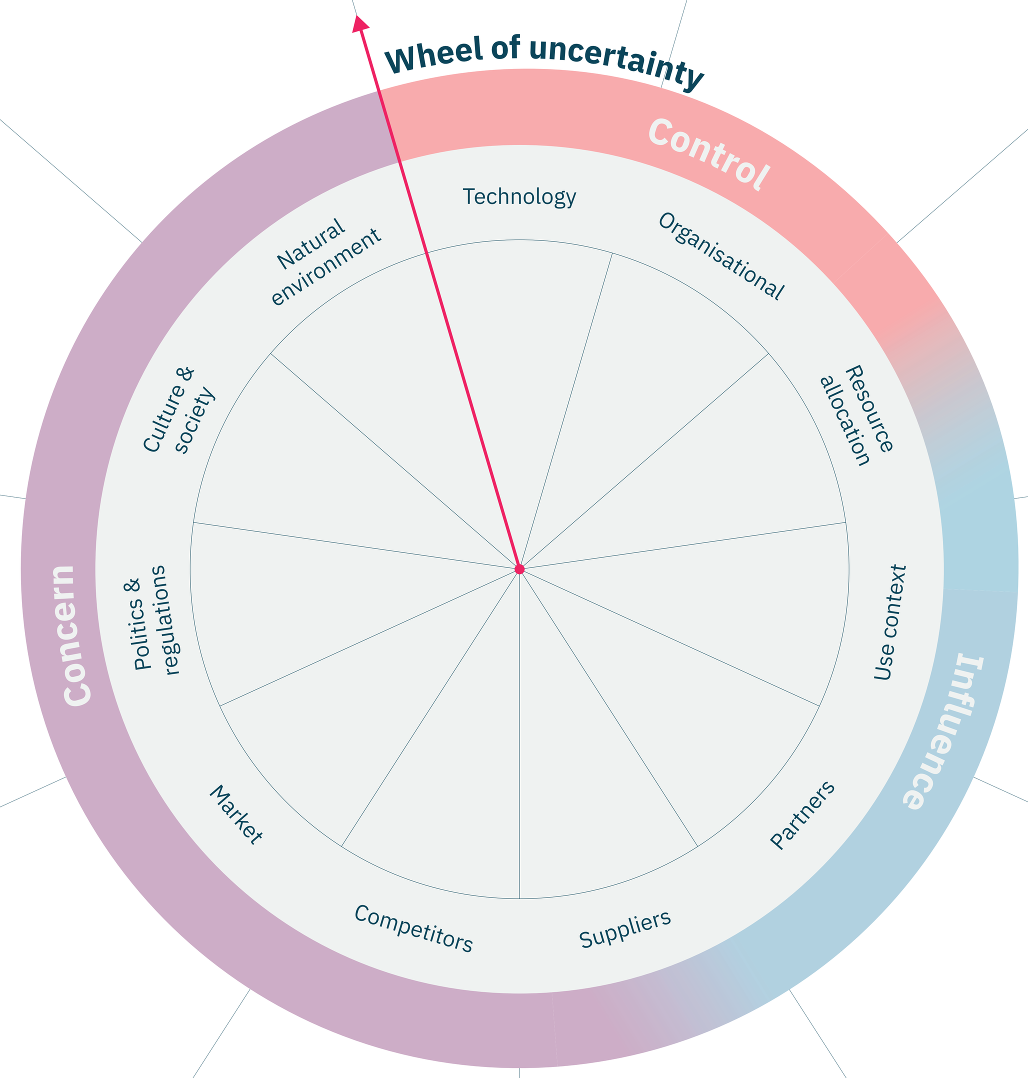
Keywords: nature, geology, weather, climate, natural disasters, natural resources

Keywords: technology, reliability, durability, interactions

Keywords: organisational context, operating team, strategy

Keywords: finances, materials, competencies

Keywords: culture, norms, values, economy, crisis



Keywords: use context, operating environment, maintenance, operator (end-user) skills and experience

Keywords: politics, regulations, legislation

Keywords: consumer requirements and needs

Keywords: competition, new product development

Keywords: suppliers, supply chain

Keywords: partners, business context, collaboration, contractual agreements

2. Reflection gate

'Do the identified uncertainties give a fair and complete representation of the project?'

- Are the uncertainties well formulated?

View page **24-25** of the Guidebook

Stage 3

Uncertainty Thinking

Body Check Analysis

Stage 3
Evaluate uncertainties

Goal: Finding the most important uncertainties & identifying their style.

Outcome: Selected core uncertainties. The style of each core uncertainty is identified as either reducible or irreducible uncertainty.

Explanation: This stage consists of two steps; 'evaluate for uncertainty/impact' and 'evaluate style of uncertainty'. After executing these two steps, the most important uncertainties (in relation to the main question in the *design brief*) have been selected (the core uncertainties) and the style of their uncertainty is identified that will help to create an action plan in the next stage.

1. Evaluate for uncertainty/impact
Each of the identified uncertainties from *stage 2* need to be evaluated for their impact (related to the main question) and their uncertainty in relation to one another. Mind that uncertainty not only includes the probability of occurrence of a situation or condition but also how a situation or condition will develop over time.

This step will help to identify the most important uncertainties that need to be coped with to achieve the goals of the proposition and the analysis (as defined in the *design brief*). After completion of this step, a slection of core uncertainties is made.

Core uncertainties are often characterised by a high uncertainty and/or high impact in relation to the goal of the analysis.

2. Evaluate the style of uncertainty
Defining the style of uncertainty allows us to more specifically assign response actions to the core uncertainties when creating the action plan. The style can be characterised by *reducible* or *irreducible* uncertainty (De Weck et al., 2007). For each identified core uncertainty needs to be indicated whether the uncertainty is reducible or irreducible.

Reducible uncertainty relates to a lack of definition or lack of knowledge, and with additional effort, this ambiguity or lack of knowledge can be reduced, as the issues are relatively well understood. Examples are the reliability of technical components, or corporate strategy and commitment (De Weck et al., 2007).

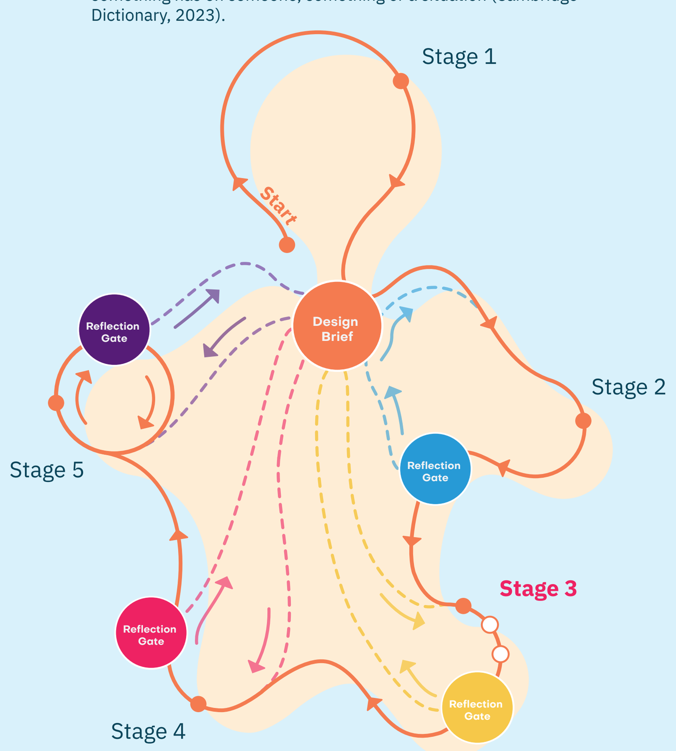
Irreducible uncertainty can only be 'explained' by the occurrence of future events. Examples are the results of a sports match, or the value of a portfolio on the stock market in a year (De Weck et al., 2007).

This step will help to identify how we can best cope with the core uncertainties. For *reducible uncertainty,* we can focus more on response actions to reduce the uncertainty. For *irreducible uncertainty*, first we should focus on monitoring to evaluate how the uncertainty is developing, and then on response actions.

Terminology - recap
Uncertainty: 'Uncertainty describes a deficiency between the amount and quality of information in possession, and the amount and quality of information required to make a decision or to perform a specific task. Moreover, it describes the presence of unknown information that could have a strong impact on the future state of a product, system or strategy and its success.'

Risk: Risk describes "an uncertain event or condition that, if it occurs, has a positive or negative effect on a project objective. A risk has a cause and, if it occurs, a consequence." (Project Management Institute, 2000, p. 127). For example, the cause may be labour shortage, the risk event is that there is no adequate labour for the task, and the consequence may be delayed project planning. The origin of risk can be found in the uncertainty that is present in all projects. (Project Management Institute, 2000; Ward & Chapman, 2003).

Impact: The impact describes a strong effect or influence that something has on someone, something or a situation (Cambridge Dictionary, 2023).



This template is part of the research 'Uncertainty Thinking - Embracing uncertainty in product development' by T.G.J. Goudsblom

1. Evaluate for Uncertainty/Impact

Use the graph on the right to evaluate the identified uncertainties for their relative uncertainty and impact. Mark the core uncertainties and place these below.

Core uncertainties:

2. Evaluate style of uncertainty

Mark the identified core uncertainties in the graph as reducible or irreducible.

Legend

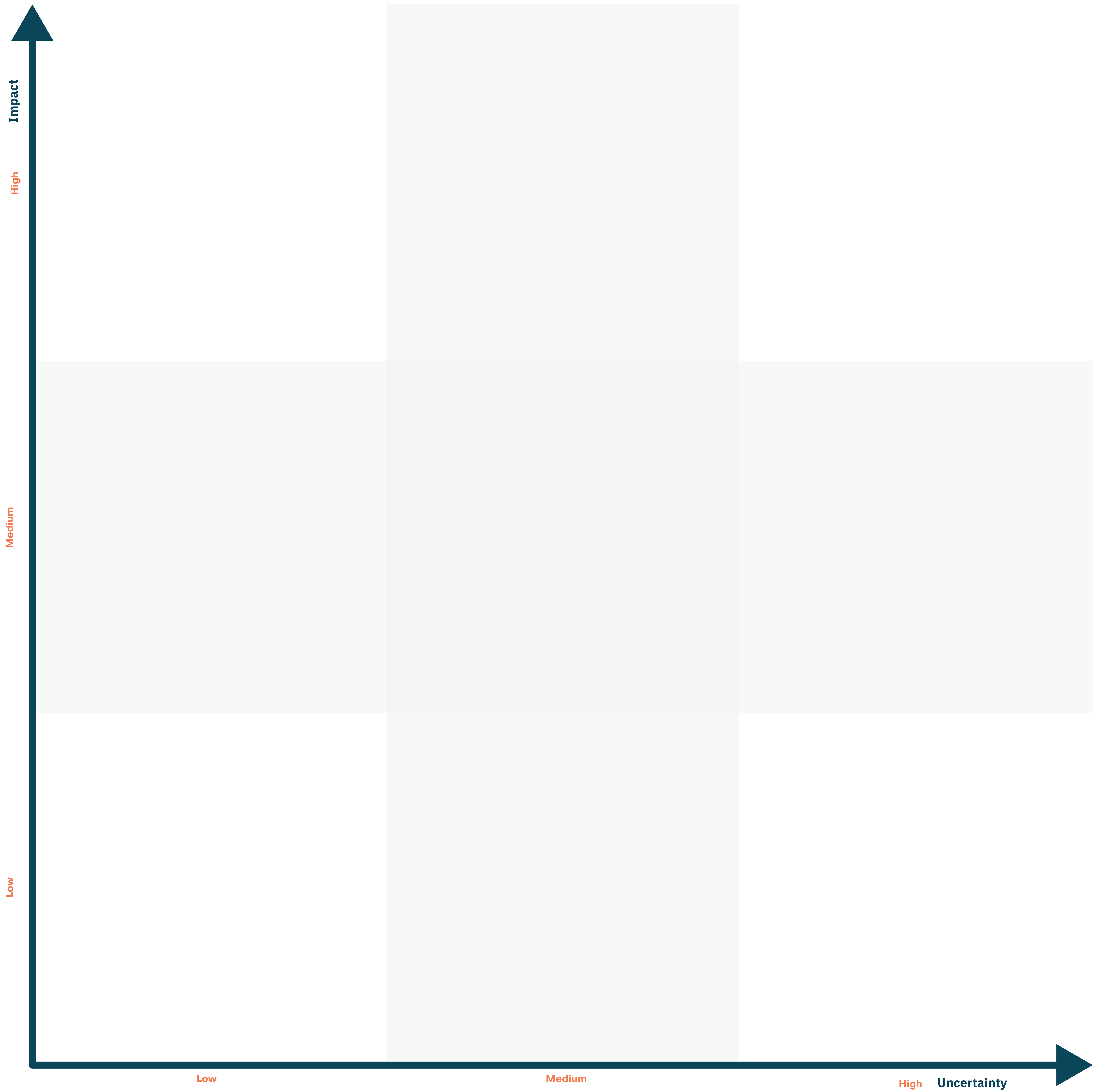
R = reducible, we can influence the uncertainty. When developing an action plan, more focus will be on creating response actions and guidelines.

I = irreducible, we cannot influence the uncertainty. When developing an action plan, more focus will be on monitoring.

Reflection gate

3. Reflection gate

'Do the identified core uncertainties address the goal of the uncertainty analysis as defined in the design brief?'



View page 26-28 of the Guidebook

Stage 4

Uncertainty Thinking

Body Check Analysis

Stage 4
Define action plan & integrate into proposition development process

Goal: Developing actions or response guidelines to cope with the identified uncertainties (core uncertainties) in the product development process.

Outcome: An action plan and/or response guidelines embedded into the way of working of the organisation.

Explanation: In this stage, actions are defined that can actively be undertaken to minimize the negative impact of the identified uncertainties. These actions are captured in the action plan and are based on the core uncertainties.

Next, this action plan is embedded into the way of working of the organisation to ensure continuity and execution of the plan.

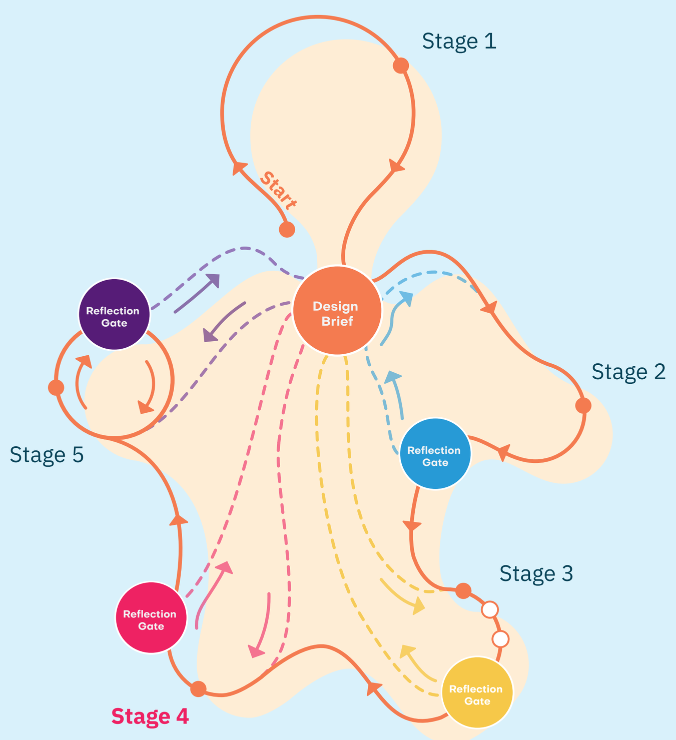
1. Creating the action plan
The action plan consists of two elements; monitoring and response actions or guidelines.

Monitoring focuses on identifying change or developments in the core uncertainty. It helps to identify whether the project is on the right track and how we should respond to the core uncertainty. Monitoring can both be activities that are actively executed (e.g. examine stakeholders preferences, investigate specific markets) or events or developments that can happen (e.g. development of new technology, launch of competitor's product, changing regulations).

Response actions or guidelines focus on how to respond to these changes and developments that can be observed through monitoring (e.g. engage field test, expand/reduce project team, train personnel at business partner, publically present project).

2. Embedding action plan into the way of working
Embed the action plan into the way of working of the organisation to ensure continuity and execution of the plan. This is done by making an agreement with the team.

Topics to think about:
1. *Responsibility*: Who is/are responsible for the execution of the plan?
2. *Reviewing the action plan*: When and how often should the action plan be reviewed (to execute the monitoring)?
3. *Decision-making*: Who needs to be involved when decisions have to be made?
4. *Validity of the action plan*: How do we determine the validity of the action plan? Or when should a new Body Check Analysis be executed?



This template is part of the research *'Uncertainty Thinking - Embracing uncertainty in product development'* by T.G.J. Goudsblom

1. Action plan

This template provides space for three core uncertainties, feel free to add extra paper if required in case there are more core uncertainties.

Core uncertainty:

Monitoring:

Response action or guideline:

Core uncertainty:

Monitoring:

Response action or guideline:

Core uncertainty:

Monitoring:

Response action or guideline:

2. Embedding action plan into the way of working

Reflection gate

3. Reflection gate

'Do the defined response actions or guidelines (the action plan) match the goal of the analysis as described in the design brief?'

- Do the defined response actions match the monitoring approach?
- Can the defined response actions and monitoring be executed as part of the way of working of the organisation?