MASTER

Data accuracy in new product portfolio management
development of a six-step guide to implement accuracy assessment

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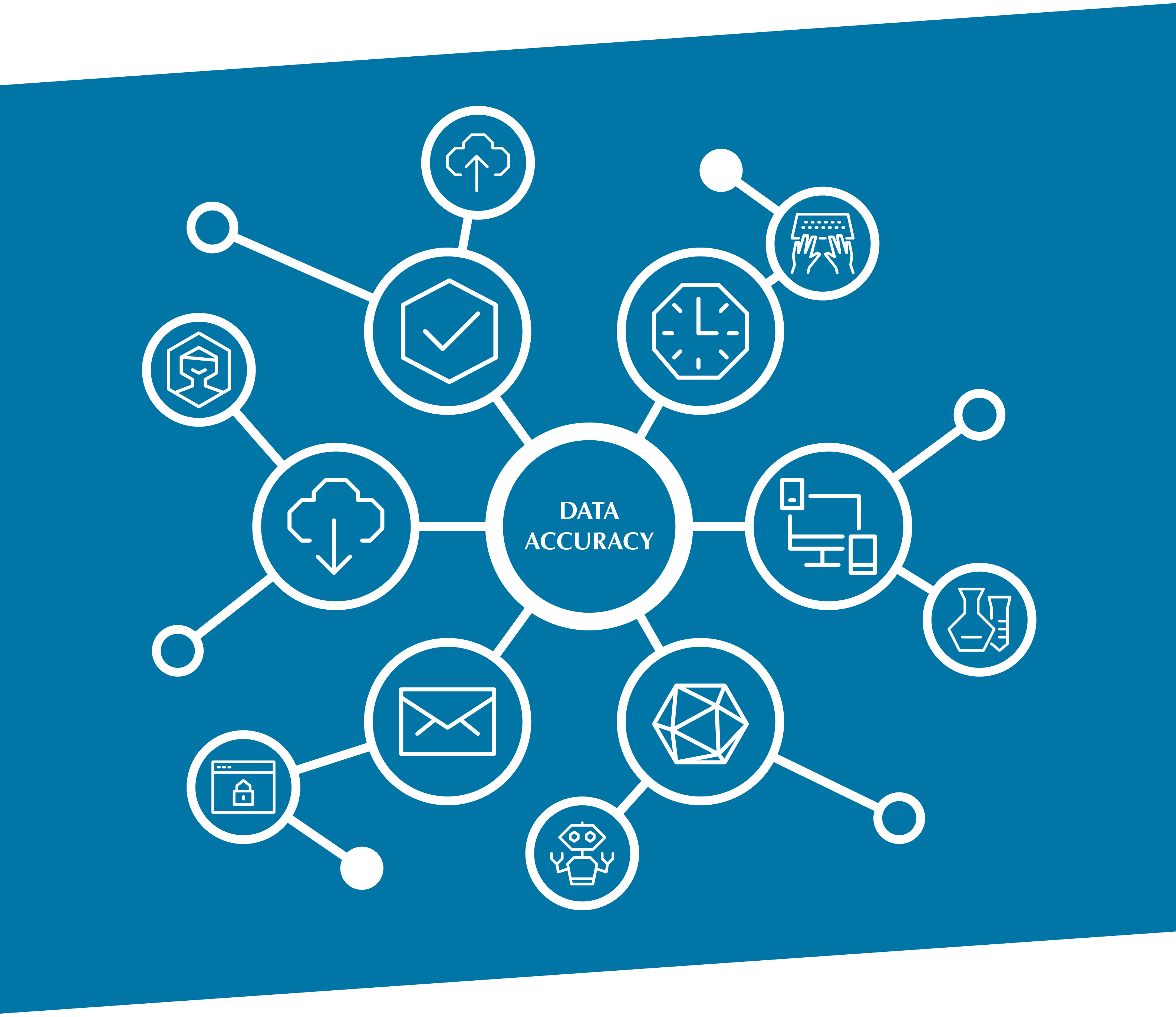

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Data Accuracy in New Product Portfolio Management

- Development of a six-step guide to implement accuracy assessment -

In partial fulfilment of the requirements for the degree of

Master of Science
in Innovation Management

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Preface

During my bachelor education Industrial Engineering, I decided to focus on the topic of innovation management. The main reason for the focus was my interest in portfolio management: "How can you select the best ideas for further development?". During my bachelor thesis, I already had the chance to dive into this topic. During this master thesis, I aimed to contribute to a solution for one of the biggest problems in portfolio management: the absence of reliable information to base decisions on. This master thesis is the final part of fulfilling the master's program Innovation Management at the Eindhoven University of Technology. In this preface, I would like to thank the people who contributed to this project.

First of all, I would like to thank my two supervisors at the university. Katrin Eling, thank you for guiding me through the process of writing a master thesis. With your knowledge in the field of new product development, and especially the ideation phase, you could answer all my questions related to this topic and provided me with feedback always very quickly. Fred Langerak, thank you for your additional feedback and introducing me to Jac Goorden and his company Bicore. This gave me the opportunity to write a thesis on a topic I really liked, and it even resulted in a first job related to this topic.

Secondly, I would like to express my gratitude to my colleagues at Bicore. Thanks to you I enjoyed coming to our office every day again. You accepted me immediately and gave me support whenever I needed it. From all of you, I especially want to thank Jac for initiating this master thesis project. Although I had no knowledge on the topic of data accuracy, you were able to get my interest on this topic right away from our first meeting at the Starbucks at the High Tech Campus. Moreover, you supported me throughout the whole project by giving direction and thinking conceptually together with me on the reasoning behind decisions I had to make. You also introduced me to multiple large high-tech organisations. This resulted in very interesting interviews about how these organisations organise their product innovation process and perform portfolio management. I really learned a lot from this!

Last, but not least, I want to thank my family and friends for their support during the time I wrote this thesis and the years before my master thesis. Thank you for supporting me to continue my education after my bachelor's program by following this master's program in innovation management.

Even though it was sometimes a big challenge to write this thesis, I really enjoyed it. I hope you will also enjoy reading it!

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Management Summary

Almost twenty years ago, inaccurate data was mentioned by well-known researchers as one of the main problems of portfolio management in new product development (Cooper, Edgett, and Kleinschmidt, 2000). Empirical research by this master thesis showed that this problem still exists. Besides data accuracy in portfolio management, the problem also exists in society in general: unreliable data has cost the US economy around $3.1 trillion in the year 2016 (IBM, 2016). This master thesis contributes to a solution to the problem of inaccurate data by providing organisations with a six-step guide in how to measure the accuracy of data and how to take the level of accuracy into account in portfolio decisions. Moreover, it provides the initiator of this research, the organisation Bicore, with an approach that can be implemented in the portfolio management software they develop.

THE IDEATION PHASE

Organisations develop products typically via a product innovation process that includes the three stages ideation, development and launch (Cooper, 1990). This research focussed on the ideation phase because portfolio management is known to be most important in this first phase of the process (Martinsuo and Poskela, 2011; Kihlander and Ritzen, 2012). In the ideation phase, ideas are generated and selected for the subsequent development phase (Heising, 2012). One of the main goals of the ideation phase is to reduce fuzziness (Chang, Chen, and Wey, 2007). Reducing fuzziness can be linked to data accuracy because knowing the level of data accuracy is assumed by portfolio managers to result in less uncertainty and thus less fuzziness.

DATA ACCURACY

Data accuracy is defined as the extent to which the value of the data represents the true value of the attribute in the real world (Caballero, Serrano, and Piattini, 2014; Laranjeiro, Soydemir, and Bernardino, 2015). This definition shows that the assessment of accuracy requires a test with the real-life object, also known as an objective approach to measure data accuracy. However, at the beginning of the new product development process, most data are forecasts of future conditions (Zahay, Griffin, and Fredericks, 2004). For this data, a test with the real-life object is not possible. This led to the need for an alternative approach to assess the accuracy of data in the ideation phase.

This alternative is a subjective approach, which measures accuracy via a survey among the data users or collectors (Pipino, Lee, and Wang, 2002). Because the level of accuracy in this approach is determined by the people that fill in the survey, the level of accuracy highly depends on the knowledge and skills of those people. To measure it even though as reliable as possible, sub-dimensions can be used. The following six sub-dimensions of accuracy are extracted from the literature and validated through interviews at large high-tech organisations.

- **Believability.** The extent to which data is regarded as true, correct, and credible.
- **Coherence.** The extent to which data is focused on one topic or one real-world object.
- **Consistency.** The extent to which data is consistent with related data.

- **Complexity.** The extent of cognitive complexity of data relative to a particular activity.
- **Objectivity.** The extent to which data is objectively collected, based on facts, and presents an impartial view.
- **Reputation.** The extent to which data are trusted or highly regarded in terms of their content or source.

PORTFOLIO MANAGEMENT

As discussed, one of the main purposes of the ideation phase is the selection of ideas for further development. This idea selection belongs to portfolio management (Kock, Heising, and Gemünden, 2015). Although portfolio management is performed during all phases of the product innovation process, it is most important in the ideation phase because good portfolio management in this phase prevents that resources in the subsequent phases are spent on ideas that later turn out to be not successful on the market (Martinsuo and Poskela, 2011; Kihlander and Ritzen, 2012). Ideas are selected on evaluation criteria (e.g. expected sales, technical feasibility, or time-to-market) that are based on data. This includes that portfolio decisions are based on these evaluation criteria, and therefore rely on the data underlying these evaluation criteria: evaluation data. The empirical research resulted in the process towards portfolio decisions, which is depicted in figure 0.1. Data is collected by different people in the organisation and just prior to the portfolio meeting stored in an information system. This can be both advanced software for portfolio management or a simple spreadsheet. Accordingly, evaluation criteria are calculated from the data and included in graphs. Lastly, the decision makers interpret the graphs of evaluation criteria and take a decision on what projects to transfer to the development portfolio.

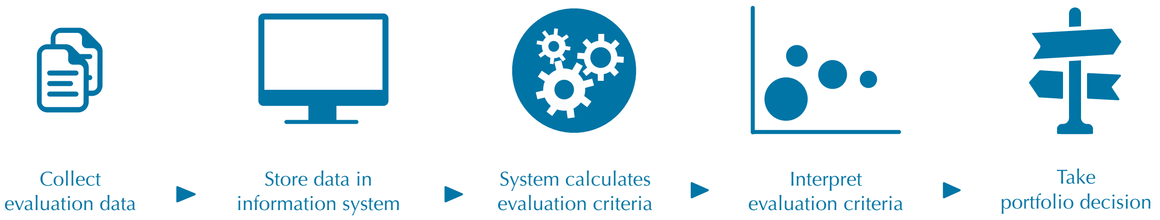

FIGURE 0.1 THE PROCESS FROM DATA TO DECISION MAKING

From the empirical research appeared that there are already some organisations that have an approach to measure the accuracy of the data. However, these approaches do not fulfil the needs of the portfolio managers. Most mentioned problems are, on the one hand, a low reliability of the estimation because the estimation highly depends on the employee that makes the estimation, and on the other hand, a lack of insights into what data exactly causes a low accuracy. Both problems are solved by using the guide presented in the next paragraph.

SIX STEPS TO MEASURE DATA ACCURACY

Because every organisation has a different product innovation process and approach to portfolio management in the ideation phase, there is not a single approach that every organisation can use to measure data accuracy. Accordingly, this research has developed a six-step guide that supports organisations in the implementation of data accuracy measurements in the process from data collection to decision making. The six activities are depicted in figure 0.2 and explained below.

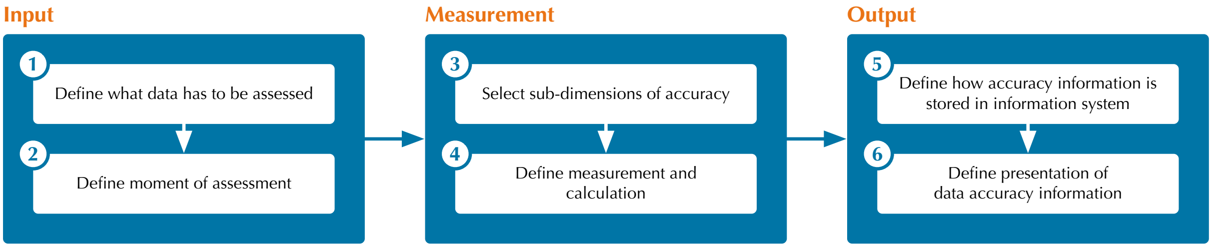

FIGURE 0.2 SIX-STEP GUIDE TO IMPLEMENT DATA ACCURACY ASSESSMENT

First, it has to be defined from what data the level of accuracy has to be measured. This is done by making an inventory of the data that has to be assessed, which can be both qualitative and quantitative data. Secondly, the moment of assessment has to be determined. An appropriate moment is when the data is entered into the information system. This because at that moment the data is formalised and the information of the source of the data is expected to be still available. Moreover, this gives the possibility to measure data accuracy again when data is added or updated, leading to a better estimation. Thirdly, sub-dimensions of accuracy have to be selected to measure data accuracy as reliable as possible. Fourthly, it has to be defined how the data is actually measured. A recommended method is a three or five-point Likert scale whereafter the sub-dimensions are averaged to an overall accuracy level of an evaluation criterion. Figure 0.3 shows a sketch of the screen in which the level of data accuracy can be measured. Fifthly, after the measurement, the level of accuracy has to be stored in the information system together with the evaluation data. Since the assessment is done for every evaluation criterion (e.g. expected market size), the accuracy level has to be linked to the concerning evaluation criterion to trace data with a low level of accuracy. Sixth and last, the presentation of the data accuracy has to be defined. Organisations can decide to present data accuracy in the graphs next to the evaluation criteria at a portfolio meeting, consider data accuracy as an additional evaluation criterion, or show for example warning-messages in case of a low data accuracy. Table 0.1 gives an overview of the six steps with recommendations.

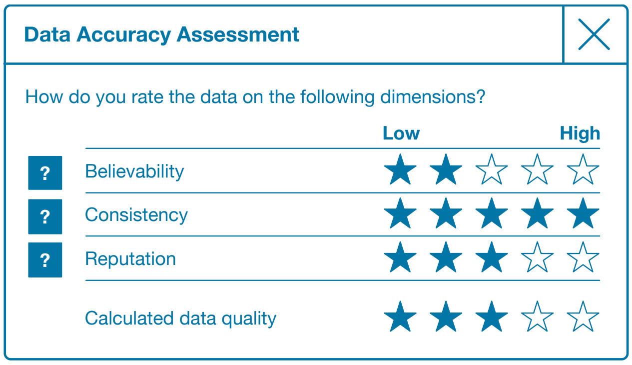

FIGURE 0.3: EXAMPLE INPUT SCREEN DATA ASSESSMENT

IMPLEMENTING THE SIX STEPS IN THE PROCESS

Implementing the six steps in the process from data to decision making causes two small additions to the process depicted in figure 0.1. At the moment the portfolio manager (or data collector) stores the evaluation data in the information system, the system asks to assess the data via several sub-dimensions of accuracy. A sketch of a potential input screen is shown in figure 0.3. After the data is assessed, the system calculates the overall level of accuracy. This overall level will be presented when the concerning evaluation criteria are retrieved from the system at, for example, the portfolio meeting. Accordingly, the decision-makers can take the level of accuracy into account by interpreting the evaluation criteria and subsequently take the portfolio decision.

CONCLUSION

Portfolio managers should use the six-step guide (figure 0.3) and corresponding recommendations in table 0.1 to define and implement accuracy measurements in their organisation. Different studies already proved that taking the accuracy of data into account leads to a better decision outcome. This six-step guide supports organisations to exploit this opportunity. By assessing the evaluation data on accuracy, the information system provides portfolio managers with an indication of on what data they can rely on and what data has a potency to improve. Accordingly, actions can be taken to improve the evaluation data in the information system, leading to more accurate evaluation criteria and better decision-making.

TABLE 0.1: RECOMMENDATIONS ON IMPLEMENTING ACCURACY ASSESSMENT

	Action	Recommendation
1	Define what data has to be assessed	- Make an inventory of the data that has to be assessed. This can be both qualitative and quantitative data.
2	Define moment of assessment	- Structure the process of data collection and storage. - Assess the accuracy of the data at the moment it is entered into the information system. - Assess the accuracy of data when data is complemented or updated.
3	Select sub-dimensions of accuracy	- Make a selection out of the sub-dimensions believability, coherence, consistency, objectivity, and reputation.
4	Define measurement and calculation	- Use a Likert scale (three or five points) to measure the sub-dimensions. - Average the sub-dimensions to establish an overall level of accuracy.
5	Define how accuracy information is stored in information system	- Store the accuracy information in the same information system as the evaluation data. - Store the accuracy information on the level of evaluation criteria in order to trace data with a low level of accuracy.
6	Define presentation of data accuracy information	- Present the accuracy information next to the concerning evaluation criteria. - Focus during the ideation phase on low accuracy levels to take correcting actions. - Show during the decision making both high and low levels of accuracy to compare projects with each other.

Contents

1 Introduction

This document presents the outcome of a master thesis research project conducted at Bicore, executed in the partial fulfilment of my master Innovation Management at the Eindhoven University of Technology. This first chapter introduces the research context, presents the research question and sub-questions, and gives an overview of the document set-up.

1.1 RESEARCH CONTEXT

Bicore develops portfolio management software to manage complex product portfolios in high-tech organisations with R&D budgets over 10 million euro per year. Although the current research is initiated by Bicore, the need for this research originated from their clients. The clients have questions regarding the accuracy of the data on which they base their portfolio decisions. Exploratory interviews and an exploratory search in literature confirmed this need, which will be discussed in the next two paragraphs.

1.1.1 Need from Practice

The main source of revenue for Bicore comes from Flightmap, a web-based software tool that organisations use to take better portfolio decisions. Flightmap has analysis capabilities to support, for example, road mapping, portfolio optimisation, project selection, and resource planning. Figure 1.1 shows a screenshot of the Flightmap software.

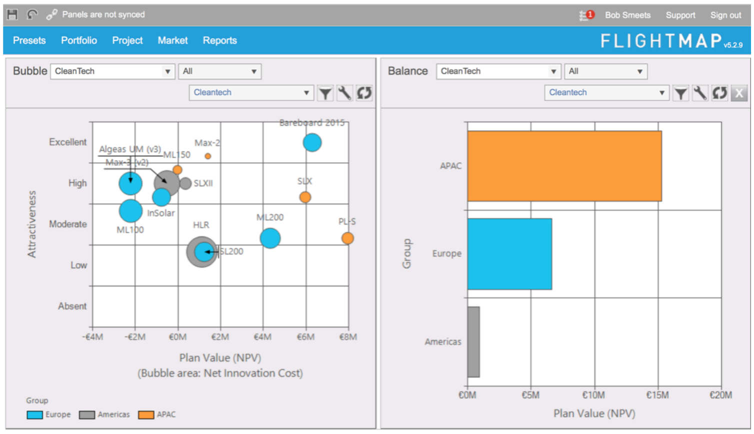

FIGURE 1.1: SCREENSHOT OF THE FLIGHTMAP SOFTWARE

Due to a lot of contact with their clients, the consultants of Bicore get insights in how large Dutch organisations in the field of new product development perform portfolio management and what difficulties these organisations experience. One of these difficulties is checking the accuracy of the data on which they base the portfolio decisions (also known as “data accuracy assessment”). Clients mentioned that they often have doubts about the accuracy of this data and therefore want to be able to assess the accuracy to take the accuracy into account in portfolio decisions. The clients assume that the current absence of insights in the accuracy of data results in a lower decision-making performance, leading to inefficient use of resources during the development of new products.

To fulfil the need of their clients, Bicore wants to extend the Flightmap software with an approach to assess the accuracy of data. To acquire knowledge in the assessment of data accuracy and how this can be implemented in Flightmap, the current research is initiated.

In the explanation above, both the terms "data" and "information" are used. These terms are related to each other because processing data results in information. Data is defined as "symbols that represent the properties of objects and events" and information is defined as "processed data" (Ackoff, 1989, pp. 1). In order to interpret data, it needs to be processed to information. Accordingly, clients of Bicore don't base their decisions directly on data but base their decisions on information (for example evaluation criteria). However, because this information is processed from the underlying data, the current research focusses on the assessment of the data. The outcome of the assessment is an indication of the accuracy of the data (for example, "high accuracy"). This indication doesn't need to be processed further and is therefore considered as information. Accordingly, the current research refers to this indication as "data accuracy information".

1.1.2 Need from Science

A search in literature did not result in any study regarding the assessment of data accuracy in new product development. However, problems resulting from data accuracy are already discussed in the literature (Strong, Lee & Wang, 1997). Cooper, Edgett, and Kleinschmidt (2000) describe unreliable data as one of the four main problems in portfolio management of new product development. They highlight the problem that managers are required to make significant investment decisions in the absence of reliable data. Accordingly, they mention the need for more research on data accuracy. Hauser, Tellis, and Griffin (2006) confirmed this need for more research on data accuracy in the context of new product development. As discussed in the paragraph above, portfolio managers expect that better decisions will be taken if they involve data accuracy information in the decision making. In the literature domain of information science, several researchers confirmed this relationship, which is strengthened by time pressure, task complexity and data quality awareness (Fischer, Chengalur-Smith, & Ballou, 2003; Shankaranarayanan, Zhu, & Cai, 2008; Moges, Van Vlasselaer, Lemahieu, & Baesens, 2016). Because no studies are found that apply the assessment of data accuracy in the context of new product development, the current research aimed to fill this gap in the literature by developing a guide for organisations to implement data accuracy assessment in the ideation phase.

1.1.3 Deliverables of the Research

The paragraphs above already mentioned the desired outcome of the current research, which is in twofold. On the one hand, Bicore wants an approach implemented in their portfolio management software to assess the accuracy of data. On the other hand, clients from Bicore and science expressed their need for a guide to implement data accuracy assessment in the context of new product development. These two deliverables are related to each other because the guide that supports the implementation of data accuracy assessment can also be used by Bicore to implement data accuracy assessment in their software. As a result, the research focussed on the development of a guide that supports organisations in the implementation of data accuracy assessment.

1.2 RESEARCH QUESTION

The current research aimed to design a guide that supports organisations in the implementation of data accuracy assessment. After implementation, organisations should be able to assess the data and take the accuracy of the data into account in portfolio decisions. These portfolio decisions are taken at the end of every phase in the product innovation process (Cooper et al., 2000). Research on the phases shows that every phase uses different data (Tzokas, Hultink, and Hart, 2004). Because this difference in data is expected to influence the assessment guide, the research focussed on one of the phases: the ideation phase. The ideation phase is the first phase of the product innovation process and is chosen for two reasons. First, the consultants of Bicore noticed that their software is used most in the ideation phase, making this phase most valuable for data accuracy assessment. Secondly, scientific research has shown that portfolio management is most important in the ideation phase (Martinsuo and Poskela, 2011; Kihlander and Ritzen, 2012). Accordingly, the following research question is defined:

"How can organisations assess the accuracy of data in the ideation phase on which they base portfolio decisions?"

To answer this research question, knowledge on three topics had to be combined. First, the ideation phase had to be examined to become familiar with the context in which the data accuracy assessment has to take place. This resulted in a need for insights into the goals and challenges of the ideation phase. Moreover, it had to be explored how organisations deal with data in the ideation phase. Accordingly, the first two sub-questions were formulated:

1. *"What are goals and challenges of the ideation phase?"*
2. *"How do organisations collect and store data in the ideation phase?"*

The other topic related to new product development that had to be examined is portfolio management. Since the current research aimed to develop an assessment guide for data on which portfolio decisions are based, knowledge was required regarding what data portfolio management needs and what portfolio management aims to achieve with this data. This led to the following sub-questions:

3. *"What is the main purpose of portfolio management in the ideation phase?"*
4. *"What data is required to perform portfolio management?"*

The last three sub-questions are related to the topic of data accuracy, being part of the information science literature. First, it had to be examined how data accuracy is defined, including what sub-dimensions of accuracy can be distinguished that can be used in an assessment guide. Secondly, it had to be clear what data accuracy information organisations need to take this into account in the development of the guide. Third and lastly, different possibilities of accuracy assessment had to be explored that can be applied to the context of new product development. Accordingly, the last three sub-questions were formulated:

5. *“How is data accuracy defined and currently taken into account by organisations?”*
6. *“What data accuracy information do organisations need in the ideation phase?”*
7. *“How can data accuracy be assessed in the ideation phase?”*

Answers to the seven sub-questions will be given in Chapter 3 and 4, as will be discussed in the next paragraph.

1.3 DOCUMENT SET-UP

This master thesis research project provides organisations with a guide to implement data accuracy assessment. The current chapter discussed the context of the research and the research questions. The next chapter, chapter 2, explains how the research is executed, following the design-based approach. Chapter 3 and Chapter 4 present the literature review and empirical research, respectively. Chapter 5 answers the sub-research questions and defines design principles and requirements. Chapter 6 presents the solution and validation of the solution. Finally, practical recommendations and theoretical implications are defined and possibilities for future research are discussed in Chapter 7.

2 Research Methodology

This chapter explains the methodology used to answer the research question and to design a solution. Because the solution will be a guide that organisations can use in practice, the research follows a science-based design approach. The next paragraph discusses this approach and subsequently, the literature review and empirical research are explained.

2.1 SCIENCE-BASED DESIGN APPROACH

This research aimed to extract knowledge from literature and apply it in practice, which made it appropriate to follow a science-based design approach as a research methodology (Romme, 2003). The science-based design approach arose from research by Simon (1988), which is later formalised to management studies by, among others, Romme (2003) and Van Aken (2004) to bridge the so-called relevance gap between scientific knowledge and practice. By following the science-based design approach, this research connected research from the field of new product development and data accuracy to managerial practice. Science-based design involves two key elements: design principles and design solutions (Romme and Endenburg, 2006). Design principles are "a coherent set of normative ideas and propositions, grounded in research that serve to design and construct detailed solutions" (Van Burg, Romme, Gilsing, and Reymen, 2008, pp. 116). These principles can be based both on practice and scholarly knowledge. The current research indicated this distinction by mentioning that a design principle is based on an answer to an empirical research question (practice), an answer to a literature review question (scholarly knowledge), or on both sources. The second key element of science-based design, design solutions, were defined as "representations of the practices begin redesign with help of design principles" (Van Burg et al., 2008, pp. 116). Design solutions are more contextualised than design principles and can be directly tested in practice. Design principles form the basis for the solutions and follow the CIMO logic to describe how to change existing situations into desired ones: in context C, use intervention I to invoke generative mechanisms M that produce outcome O (Denyer, Tranfield, & Van Aken, 2008). Besides the design principles, a second input for the solution were design requirements (van Aken, Verends, and Van der Bij, 2012). Design requirements are conditions that the solution has to meet. In contrast to the design principles, design requirements were only based on knowledge from practice.

The science-based design approach was translated into the research process explained below.

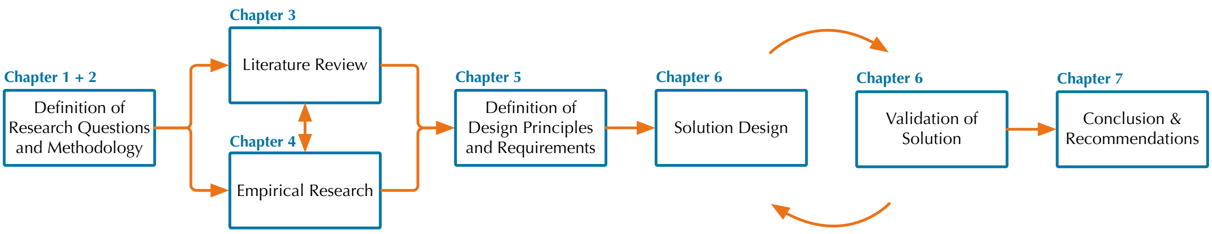

FIGURE 1.2: RESEARCH PROCESS

Because the answers to the research questions required both knowledge from literature and practice, the questions were translated to literature review questions and empirical research questions. These were answered by the literature review and empirical research. Next, combining the answers to the literature review and empirical research questions led to answers to the sub-research questions which were translated into design principles and design requirements. On these design principles and requirements, the solution was based. Next, the solution was validated via additional interviews. This led to some input for the final solution, which was discussed together with the implications in the last chapter of the research. The next two paragraphs discuss the set-up for the literature review and empirical research.

2.2 LITERATURE REVIEW

To answer the research question, a literature review was conducted in parallel with empirical research. This paragraph explains the methodology that was used for the literature review. The review focused on the same topics as the sub-research questions: the ideation phase, portfolio management, and data accuracy. Accordingly, the sub-research questions were translated to literature review questions (table 2.1). In the literature review itself (Chapter 3), the questions are explained further.

TABLE 2.1: LITERATURE REVIEW QUESTIONS BY RESEARCH TOPIC

	Literature Review Question
Ideation Phase	"How does the ideation relate to the other phases of the product innovation process?"
	"What is the purpose of the ideation phase?"
	"What are the main challenges of the ideation phase?"
	"What types and sources of data do organisations use in the ideation phase?"
Portfolio Management	"What is decision making and how does it relate to the ideation phase?"
	"What is portfolio management and how does it add value to an organisation?"
	"On what criteria are ideas or projects selected?"
Data Accuracy	"How is accuracy defined?"
	"How can accuracy be measured?"

The next two paragraphs explain the methodology that was used to answer the literature review questions above.

2.2.1 Search Strategy

The search in the literature was conducted via two search strategies: the keyword strategy and the snowballing strategy (van Aken et al., 2012). The keyword strategy was applied first to find articles that helped to answer the research questions. This started by making a list of keywords for the searches. These keywords were derived from a search through key articles and exploratory interviews with consultants at Bicore and with experts in new product development. The search was performed with the keywords (1) "new product development", (2) "product innovation process", (3) "ideation phase", (4) "portfolio management", (5) "decision making", (6) "data quality", (7) "data accuracy", (8) "measuring data quality". The keywords and combinations of keywords (for example, "ideation phase data accuracy" or "portfolio management new product development") were used in the search engines "Web of Science" and "Google Scholar". The search was ended when no more relevant articles were found.

Subsequent to the keyword strategy, the snowballing strategy was used (Aken et al., 2012). Via this strategy, the number of articles was expanded, both via forward and backwards snowballing. Forward snowballing was carried out via the SSI (accessed through the "Web of Science" and "Google Scholar") to find later articles that refer to the key publication. Backwards snowballing was performed by searching through the references of already found articles. Similar to the keyword strategy, the snowballing strategy was ended when no more relevant new articles were found. Unanswered research questions gained additional attention in the empirical research, which will be discussed later.

2.2.2 Selection Criterion

Before the literature search was conducted, selection criteria were determined to ensure the articles had a sufficient quality and were related to the research topic. Accordingly, the criteria consisted both of quality- and content related requirements. To ensure a sufficient quality of the articles, on "Web of Science" the journal impact factors were checked and at "Google Scholar", the number of citations were checked. Exceptions were made to articles related to data accuracy because these were often included in journals without an impact factor. Content-related requirements were defined to make sure the included literature was relevant to the topic of the research. The articles had to focus on data accuracy in general or on new product development, preferably in a high-tech context to match the clients of Bicore and organisations involved in the empirical research.

The search process discussed above resulted in the literature review (Chapter 3), which is supplemented and verified via empirical research on which the method will be discussed in the next paragraph.

2.3 EMPIRICAL RESEARCH

Besides the knowledge from the literature, also knowledge from practice was needed to answer the research question. This knowledge was acquired via semi-structured interviews. The current paragraph describes the choice for interviews and the methodology that was used. Empirical research was conducted for three reasons. First, additional knowledge had to be extracted from practice to answer all the sub-research questions and subsequently define design principles. Secondly, the empirical research aimed to validate findings regarding data accuracy from the domain of information systems in the domain of new product development. Thirdly, the deliverables were verified via empirical research to make sure they answered the research question. As already discussed, the empirical research was guided by empirical research questions (table 2.2). These questions followed, on the one hand, directly from the sub-research questions to validate findings from the literature review and, on the other hand, from the gaps that were discovered in the literature review.

TABLE 2.2: EMPIRICAL RESEARCH QUESTIONS BY RESEARCH TOPIC

	Empirical Research Question
Ideation Phase	"Do all organisations have an ideation phase and go-to-development gate?"
	"How do organisations collect and store data in the ideation phase?"
Portfolio Management	"How do organisations take portfolio decisions?"
	"What data do organisation need to take portfolio decisions?"
	"What are the sources of data organisations use to take portfolio decisions?"
Data Accuracy	"Do organisations currently take the accuracy of data into account?"
	"What sub-dimensions of accuracy can portfolio managers think of?"
	"What data accuracy information do organisations need at what moment?"
	"What is the best moment to measure the accuracy of data?"

The next paragraphs discuss the empirical research in more detail, i.e. the unit of analysis and case selection, data collection, and data analysis.

2.3.1 Unit of Analysis and Case Selection

To obtain a detailed and reliable insight into the practices of the interviewees, the unit of analysis, the context, and the time boundaries of the research were determined (Yin, 2003). Yin defined the unit of analysis as the subject of the research. For the current research, this was the data on which evaluation criteria are based that support portfolio decisions. In the remaining of the report, this data is called "evaluation data". The context of this study was the process of the collection of data till the evaluation of an idea in the ideation phase. The evaluation takes place in the go-to-development gate, which was for this research considered as being the end of the ideation phase. Accordingly, the time boundaries of the current research were the start and end of the ideation phase.

Following the explorative character and focus on contemporary events of the current research, a multiple case study research is well-suited (Yin, 2003). The cases were found in the network of Bicore because the research was initiated to fulfil the need of Bicore's clients. To be included in the research, the cases had to meet two criteria. First, following the context of new product development, the organisation should develop products or services using a product innovation process. Secondly, the organisation should take portfolio decisions based on data at the end of the ideation phase. According to the guidelines by Yin (2003) for a multiple case study, six to ten cases had to be included in the research. After discussing the criteria with the consultants of Bicore, a list of eight cases was established, covering six organisations. To ensure the sample size was large enough, the data was checked after analysis on saturation (Morse, 1995). For every case, a portfolio manager was interviewed to make sure that all questions regarding portfolio management could be answered.

2.3.2 Data Collection

To establish triangulation of data and accordingly increase construct validity, different sources of data were used (Yin, 2003). First, before an interview was conducted at the organisation, the case was discussed with the account manager or salesperson at Bicore to acquire background information on the case for preparation of the interviews and validation of the results. Secondly, most data was collected via semi-structured interviews, conducted using an interview guide (Appendix A). This guide consisted of 21 open questions that were asked to the interviewees. A long time interval between the examination of the sixth and seventh case gave the opportunity to develop a preliminary solution and verify this solution at the end of the last two interviews. Thirdly, during the interviews, the interviewees were asked for documentation supporting their answers. Accordingly, for most cases, documentation was reviewed. Because of high confidentiality, the documentation could not be stored in the database with findings of the empirical research.

2.3.3 Data Analysis

The eight interviews were recorded and transcribed for data analysis. Because the interviews were semi-structured and the interview guide consisted only of open questions, the data was unstructured (e.g. data on topic B was collected in the questions on topic A). Accordingly, the data was structured via coding (van Aken et al., 2012). The coding was started by using a coding template (Appendix B) derived from the empirical research questions. The coding template aimed to link the data to a topic and consisted of a coding category (e.g. data accuracy), specific category (e.g. current data accuracy approach) and keywords (e.g. accuracy check). Subsequently, the open coding strategy was used, which added new codes during the coding process (van Aken et al., 2012). The open coding strategy is part of the grounded theory approach which aims to develop concepts and discover relationships between concepts. This led, for example, to the development of a general process of how evaluation data is collected, processed and used. Moreover, the open coding strategy supported the definition of accuracy sub-dimensions.

Following the process of Eisenhardt (1989), the data analysis was conducted at two levels. First, the cases were analysed individually in the within-case analysis to discover unique patterns for each case before generalising. Secondly, cross-case patterns were identified over the eight cases, which was supported by the coding. The outcome of the cross-case analysis is discussed in the empirical research of Chapter 4.

2.4 CONCLUSION

This chapter described how the research process followed the science-based design approach to extract knowledge from literature and combined it with findings from empirical researching to apply it into practice via a solution. For the external validity of the research, the literature search strategy was discussed and it was explained how the empirical research is conducted. Following the research process, the next chapter describes the key results of the literature review and gives answers to the literature review questions.

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3 Literature Review

The literature review presented in this chapter aimed to acquire knowledge in the field of the ideation phase, portfolio management, and data accuracy. Accordingly, these three topics are discussed in the three paragraphs of this chapter, starting every paragraph with the introduction of the literature review questions that the paragraph aims to answer. When a question is answered, the answer is given in a blue box. The main contributions from the three topics are outlined in the conclusion of this chapter.

3.1 THE IDEATION PHASE

As discussed, the current research aimed to develop an assessment guide for data in the ideation phase. To take the context of the current research into account in the development of this guide, this paragraph provides an overview of the ideation phase. This was done via four literature review question, listed and discussed below:

1. *"How does the ideation relate to the other phases of the product innovation process?"*
2. *"What is the purpose of the ideation phase?"*
3. *"What are the main challenges of the ideation phase?"*
4. *"What types and sources of data do organisations use in the ideation phase?"*

Because portfolio decisions in the ideation phase influence other phases of the product innovation process, first literature on the product innovation process was reviewed. Subsequently, the purpose of the ideation phase was described to acquire knowledge of the context of the data that has to be assessed. Similarly, an overview of current challenges in the ideation phase was made to discover links with data accuracy and potential input for the development of an assessment guide. Lastly, literature on data collection was consulted to discover how organisations collect data in the ideation phase since the assessment guide had to be embedded in the process of data collection.

3.1.1 The Product Innovation Process

All innovations start with an idea; an opportunity to create value via further investment (Terwiesch and Ulrich, 2009). This can be the recognition of a new need, a new concept as a solution for an existing need, or a conjecture that an existing solution could meet an emerging need (Kornish and Ulrich, 2014). The process many innovations follow is called a product innovation process (Kahn, 2002).

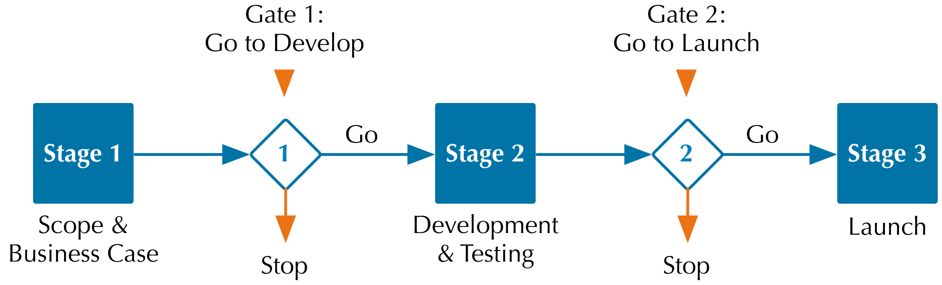

FIGURE 3.1: EXAMPLE OF PRODUCT INNOVATION PROCESS (ADAPTED FROM COOPER, 1990)

Via a product innovation process, ideas are generated and selected in the ideation phase, transferred to the development portfolio where they are developed into products, and finally launched to the market. There are many forms of product innovation processes, figure 3.1 gives an example. The first stage in this example has the function of the ideation phase. Research has shown that about 74% of firms have a formal product innovation process and about 58% of firms use clearly defined evaluation criteria after each phase (or stage). These numbers are very different for best and worse performing companies; 90% of best-performing companies have a formal process in place, in contrast to 44% of worse performers (Cooper and Edgett, 2012). The best-known model of a product innovation process is the Stage-Gate® system, created by Robert Cooper in the 1980s. The model was based on an in-depth study of successful "intrapreneurs" within major cooperations (Cooper, 2014). The goal of a product innovation process is to reduce the uncertainty along the way from idea generation to launch. In the beginning of the process, there could be a lot of ideas. Less promising ideas could be eliminated right away, more promising ideas are converted into concepts. Only the best concepts make it into development. Although the process was depicted as a sequential process, stages can overlap each other and can be started over after a gate meeting (Crawford and Di Benedetto, 2010). By comparing the ideation phase with the subsequent development phase, the main difference appeared to be that the development phase is more structured and has a higher certainty than the ideation phase. Thus, the ideation phase can be described as being fuzzier and less structured (Koen, Ajamian, Boyce, Clamen, Fisher, Fountoulakis, and Seibert, 2002).

Because the world has changed a lot since the first Stage-Gate system of Robert Cooper, the system attracted some criticism: the system was often not able to keep up with the faster innovation speed, unable to handle more dynamic projects, and it got the criticism to be too controlling and bureaucratic (Becker, 2006; Lenfe and Loch, 2010). As a response to this, Robert Cooper has recently revised the Stage-Gate system and made it more agile, flexible and dynamic (Cooper, 2014). Also, a "Lite" (figure 3.1) and "XPress" version of the system was made, consisting of three and two stages, respectively. For the shortest process, this caused that only the go-to-development gate is left. The endurance of this gate shows the importance of it and contributes to the relevance of the focus of this research on the ideation phase, including the go-to-development gate. More reasons for the importance of the ideation phase are given in the next paragraph, that discusses the goals of this first phase of the product innovation process.

Answer to literature review question 1:

"How does the ideation relate to the other phases of the product innovation process?"

In general, every organisation develops their own product innovation process leading to the existence of many different processes. However, in general, the ideation phase always exist. In the ideation phase, ideas are generated and selected to be further developed in the subsequent phases, which shows the link with the other phases. By comparing the ideation phase with the subsequent development phase, it became clear that the ideation phase is less structured and has more uncertainties. These uncertainties can be linked to the difficulties regarding the accuracy of data in the ideation phase that portfolio managers experience.

3.1.2 The Purpose of the Ideation Phase

The ideation phase is in literature also called the "front end" of innovation because it contains the early phases of the innovation process. Resulting from the existence of different innovation processes in companies, there is a debate in the literature about what activities belong to this part of the innovation process. For example, the front end was conceptualised by Koen, Ajamian, Burkart, Clamen, Davidson, D'Amore, and Karol (2001) as the activities that are executed before a structured process takes place. Khurana and Rosenthal (1998) on the other hand, defined the front end as the phase that ends when a concept, a feasibility study, and a project planning are made and the idea is ready to be judged in the "Go to Development" gate. This is in accordance with the definition of Heising (2012) who stated that the ideation phase consists of three stages: "*(1) ideation in its narrow sense of identifying opportunities and generating ideas, (2) evaluating and selecting these ideas, and (3) condensing, clustering and bundling these ideas into proposals for new projects or changes in the scope of existing projects*". The ideation phase ends when the project proposal is completed and a formal decision can be made with respect to the further development of the idea. If the proposal is accepted, the idea is integrated into the project portfolio (Heising, 2012). This explanation of the ideation phase corresponds to the view of the ideation phase as introduced in the previous chapter and the context of this research. Hence, the present study sticks to this definition by Heising (2012). Now the purpose of the ideation phase is determined, the next paragraph explains the challenges organisation face in this phase.

Answer to literature review question 2:

"What is the purpose of the ideation phase?"

In the literature is a debate on the purpose of the ideation phase. The current study sticks to the definition by Heising (2012) who defined that the ideation phase identifies opportunities and ideas, evaluates and selects ideas, and lastly bundles these ideas into proposals for new projects.

3.1.3 Challenges of the Ideation Phase

In the literature, two main challenges of the ideation phase are described: reducing fuzziness and accelerating the ideation phase. Fuzziness in the ideation phase can be described as uncertainty and equivocality (Doll and Zhang, 2001). To reduce the amount of fuzziness in the ideation phase, it is important to take into account where fuzziness occurs from. Fuzziness can result from the environment, the activities that are conducted, and the goals that are set. Chang, Chen, and Wey (2007) defined four activities to reduce fuzziness, including assessing fuzziness on project level and accumulate acquired information for future innovations. Reducing fuzziness is related to accelerating the ideation phase because methods that reduce fuzziness reduce the lead time of the ideation phase. Moreover, methods that reduce the lead time improve the probability of success of this phase (Kim and Wilemon, 2010). These methods can be divided into two categories: methods that enhance the internal ideation competency and methods that enhance the external ideation competency. Internal competencies refer to organisational capabilities to reduce fuzziness. External competences imply capabilities to collect information about markets, customers, and competitors to reduce fuzziness.

Due to the importance of accelerating the ideation phase, more researchers focused on this topic. Already in 1994, Reinertsen gave attention to accelerating the ideation phase by emphasising that the ideation phase is the best part of the innovation process to accelerate since it consumes a lot of time. Reinertsen (1994) made a list of the ten most common problems in the ideation phase, which relate to strategy, the implemented process, and a lack of resources. Another study about accelerating the ideation phase was performed by Thomke and Fujimoto (2000). They wrote an article about executing tasks in the innovation process as early and quickly as possible, which they called “front-loading”. The authors described several methods by which this can be achieved. The two most important ones are project-to-project knowledge transfer and rapid problem-solving.

Although the studies above focused on accelerating the ideation phase, there is ambiguity in the literature whether this is in favour of the new product performance or not (Eling, Langerak, and Griffin, 2013). On the one hand, literature argues that an acceleration of the innovation process improves performance because environmental and technical forces can be better forecasted which results in a product that fits better in the market. Additionally, a shorter time-to-market results in more sales because of a longer product life cycle and the achievement of pioneer or fast-follower advantages. On the other hand, accelerating the innovation process can result in entering the market too early and it can lower the new product performance when steps in the innovation process are skipped. Eling et al. (2013) investigated this ambiguity and came to the conclusion that accelerating the ideation phase is only advantageous for new product performance in case all phases of the innovation process are accelerated. A way to achieve this is by implementing a time-to-market strategy in all phases of the innovation process.

Answer to literature review question 3:

“What are the main challenges of the ideation phase?”

The two main challenges described in the literature are reducing fuzziness and accelerating the ideation phase. These challenges are related to each other because methods that reduce fuzziness also reduce the lead time of the ideation phase. Fuzziness can be linked to data accuracy, because not knowing whether data is accurate leads to uncertainty and is thus a source of fuzziness. In case data accuracy assessment shows that data has a high accuracy, it reduces fuzziness and can accelerate the ideation phase since no additional data has to be acquired.

3.1.4 Data Use in the Ideation Phase

As described above, one of the main challenges in the ideation phase is fuzziness, which is related to uncertainty. Accordingly, decision making in the ideation phase is challenging due to the high amount of uncertainty, which is mainly caused by a lack of data in this phase of the innovation process (Riel, Semeijn, Hammedi, and Henseler, 2011). In the context of portfolio management in new product development, two categories of data can be distinguished (Kelly and Storey, 2000):

- **Internal data.** Data that is available from within the organisation and contributes to a better understanding of the positioning of the new product within the existing portfolio.
- **External data.** Externally collected data that helps decision makers to judge the commercial value and technical quality of the new product.

These two categories can be extended by a third category; data that is externally obtained and internally developed (Zahay, Griffin, and Fredericks, 2004). An example of this data are technical specifications that are developed from requirements mentioned by customers (e.g. the requirement from a customer to use a mobile phone for a day without charging, results in the specification of a particular battery capacity). Zahay et al. discovered eight types of data regarding new product development, distributed over three categories. In a later research, they expanded the eight types by one type, resulting in the nine types depicted in figure 3.2 (Zahay, Griffin, and Fredericks, 2011).

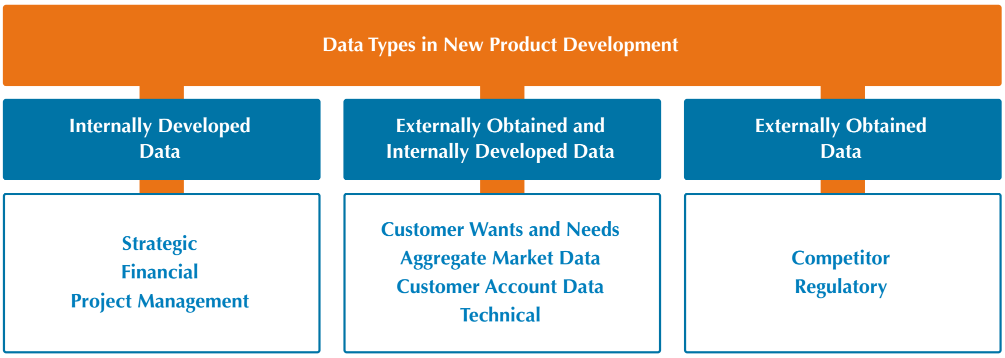

FIGURE 3.2: DATA TYPES IN NEW PRODUCT DEVELOPMENT (ADAPTED FROM ZAHAY ET AL., 2011)

The ideation phase is the only phase of the development process where all the different types of data are used (Zahay et al., 2004). From the nine types, strategic, market, and regulatory data are used most in the ideation phase. The use of another type of data, customer account data, is in the ideation phase directly associated with market success (Zahay et al., 2011). Also, logistic regression showed that best-performing firms use more strategic and technical data in the ideation phase. This showed that best-performing firms tend to align the project strategy with organisational strategy and provide projects with technical data already in the beginning of the product innovation process. Although the ideation phase is the only phase where all the different types of data are used, it is also the phase with the lowest information use. This is interesting since this phase is known for its highest uncertainty, leading to the presumption that the amount of used information is high in order to lower the uncertainty. A possible explanation for this can be that teams start the ideation phase with only the limited data that is available at hand (Cooper, 1999).

The use of market data in the ideation phase is directly associated with market and financial success (Veldhuizen, Hultink, and Griffin, 2006). In addition to this direct relationship, the researchers also found some indirect effects for components of market data on product advantage and product success. An example is that the acquisition of customer and environmental data leads to an increase in dissemination across the firm. In turn, increased dissemination of market data is associated with increased data use in the ideation phase of the innovation process which leads subsequently to new product advantages. This relationship resulted in the recommendation to innovation managers to ensure that enough market data is provided to or collected by the new product development team (Veldhuizen et al., 2006).

To understand data use in the ideation phase, it is also important to understand how data enters the firm. There is a difference in this data flow for incremental, as compared to radical innovations (Brentani and Reid, 2012). For incremental innovations, problems or opportunities are from within the organisation directed to individuals to gather more data in the environment. For radical innovations, data is received from the environment by individuals and brought into the organisation where it has to pass several gatekeepers and is tested with the organisational strategy before a decision is made.

Answer to literature review question 4:

"What types and sources of data do organisations use in the ideation phase?"

In general, three categories of data can be distinguished that organisations use in the ideation phase: (1) internally developed data, (2) externally obtained data, and (3) data that is externally obtained and internally developed. Nine types of data are spread over these categories, from which strategic, market, and regulatory data are used most in the ideation phase. The categories already mention that data in the ideation phase can both be acquired from inside or outside the organisation.

This question regarding data use is the last literature review question related to the ideation phase. The next paragraph explores the literature of new product development further, looking at the selection of ideas or projects in the ideation phase, which is also known as ideation portfolio management.

3.2 PORTFOLIO MANAGEMENT

In the previous paragraph, some activities of the ideation phase are mentioned. The most important tasks of the ideation phase are idea and concept evaluation (Martinsuo and Poskela, 2011). This includes the evaluation and ranking of ideas or concepts whereafter a decision is made to stop or to continue with the idea or concept. These activities are part of portfolio management, which is most important in the ideation phase of the product innovation process (Cooper et al., 2000; Martinsuo and Poskela, 2011; Kihlander and Ritzen; 2012). Since the assessment guide aims to improve decision making in portfolio management, the literature on portfolio management had to be taken into account in the development of the guide. This was done via three literature review questions, listed and discussed below.

5. *"What is decision making and how does it relate to the ideation phase?"*
6. *"What is portfolio management and how does it add value to an organisation?"*
7. *"On what criteria are ideas or projects selected?"*

To answer the literature review questions, first, the literature on decision making in the ideation phase was consulted to acquire background knowledge on types of the decisions and how decision making can be influenced. Secondly, the literature on portfolio management was examined to explore the context of the research. Lastly, criteria were examined on which ideas are evaluated because the data underlying these criteria has to be assessed.

3.2.1 Decision Making in the Ideation phase

A decision-making process can be defined as a process consisting of four stages: intelligence, design, choice, and implementation (Simon, 1960). Decisions can be categorised as structured, semi-structured, and unstructured. Structured decisions have a known procedure for handling them, resulting in routine actions and known situations. Unstructured decisions are opposite, there is no procedure known to solve the problem and the decision makers must provide judgement, evaluation, and insight. Decisions that have both structured and unstructured elements are called semi-structured. These decisions can be partly answered via predefined procedures (Gorry and Morton, 1989).

The main purpose of decision making in the ideation phase is selecting the right ideas for further development. This requires assessing both the potential of the individual idea at the project level and the idea's potential contribution to the firm's NPD portfolio (Eling, Griffin, and Langerak, 2016). In general, this selection happens twice during the ideation phase (Hammedi, van Riel, and Sasovova, 2011). First, the ideas are screened in order to exclude ideas that will probably not lead to successful products. Ideas that have a substantial chance of success are selected for further analysis. These ideas are typically developed into a concept whereafter they are evaluated again. Subsequently, the most promising concepts are transferred to the development phase and become part of the project portfolio (Hammedi et al., 2011; Cooper, 1999; Crawford and Di Benedetto, 2010). Paying attention to this decision-making process appears to be important because the level of flexibility and strictness has to be balanced carefully. If too many projects are selected for further development, the chance increases that time and resources are spent on failing products or that successful products receive not enough resources. However, use of too rigid evaluation criteria can also have a negative effect because it might hinder selecting potential successful radical ideas (Sethi and Iqbal, 2008).

Decision-making in the ideation phase can also be divided into formal and informal approaches (Holahan, Sullivan, and Markham, 2014). Formal selection procedures may be beneficial for incremental products because less innovative ideas allow for more standardised procedures. This in contrast to radical ideas, that need informal methods for selection because predefined criteria and gate meetings may filter out radical ideas (Bonner, Ruekert, and Walker, 2002; Sethi and Iqbal, 2008). Recent research by Eling et al. (2016) however showed that the consistent use of formal processes for both incremental and radical ideas leads to the highest firm's idea success rate. This can be explained by the importance of adopting a portfolio view during the ideation phase (Kock, Heising, and Gemünden, 2015). The next paragraph discusses this portfolio view.

Answer to literature review question 5:

"What is decision making and how does it relate to the ideation phase?"

Initially, decision making is defined to consist of the four stages intelligence, design, choice, and implementation and can be categorised as structured, semi-structured, and unstructured decisions. In the ideation phase, decision making entails selecting the right ideas for further development and can be divided into formal and informal approaches. Recent literature concluded that consistent use of formal processes for both incremental and radical ideas leads to the highest firm's idea success rate.

3.2.2 Portfolio Management in the Ideation Phase

Adopting a portfolio view implies that firms should not only take the advantages of the individual projects into account but take also the contribution of an idea to the firm's entire NPD portfolio into account. In the ideation phase, this can be achieved by an ideation portfolio approach, which consists of management practices that enable the generation of many diverse ideas while simultaneously allowing for the selection and prioritisation of most promising ideas to be introduced into the project portfolio (Kock et al., 2015). Ideation portfolio management was conceptualised by three elements that represent its basic managerial practices: (1) creative encouragement, (2) process formalisation and (3) alignment of the idea generation and selection activities with the innovation strategy.

The performance of selecting the right ideas in the ideation phase can be measured via the idea success rate (Hammedi et al., 2011). This refers to the proportion of selected ideas that are ultimately developed into successful products. The performance can also be measured via screening effectiveness, which means achieving the desired outcome, which can be measured in quality or strategic fit (Hammedi et al., 2011). Screening effectiveness can also be defined as minimising the two types of potential errors: Type I and Type II errors. Type I errors occur when resources are spent on failing products (De Brentani and Droge, 1988) and Type II errors occur when ideas of successful products are ignored (Baker and Albaum, 1986).

The overarching concept of the earlier introduced concept of ideation portfolio management is project portfolio management. According to Cooper (2001), project portfolio management has three objectives: maximising the value of the portfolio, linking the portfolio to firm's strategy, and balancing the portfolio. More recently, Jonas, Kock and Gemünden (2013) split the objective to maximise the value of the portfolio into the maximising the average project success over all the projects in the portfolio and maximising the exploitation of synergies between projects within the portfolio. In accordance to Kock et al. (2015), well-performed project portfolio management leads to high project portfolio success that consists of the five dimensions mentioned in table 3.1.

TABLE 3.1: DIMENSIONS OF PROJECT PORTFOLIO SUCCESS (ADAPTED FROM KOCK ET AL. 2015)

Dimension	Explanation
Business success	Impact of the portfolio on the firm's business performance
Average economic success of products and project results	Success on the individual product or project level
Strategic fit	Degree to which all projects combined are consistent with and reflect the organisation's business strategy
Portfolio balance	Strategic perspective of balancing existing and new technologies and application areas with the project portfolio
Preparing for the future	Benefits and long-term opportunities for the organisation that are rooted in the project portfolio

Firms use different methods for portfolio management. The five most used methods are financial methods, business strategy, bubble diagrams, scoring models, and checklists (Cooper, 2001). In line with the dimensions mentioned in table 3.1, Cooper et al. (2000) defined four goals of portfolio management: (1) maximise the value of the portfolio, (2) seek balance in the portfolio, (3) strategic alignment of the portfolio, and (4) select the right number of projects. The selection of ideas or projects is supported by evaluation criteria, which will be discussed in the next paragraph.

Answer to literature review question 6:

"What is portfolio management and how does it add value to an organisation?"

Adopting a portfolio view implies taking the contribution of an idea to the firm's project portfolio into account, besides the advantages of the individual project. Well-performed project portfolio management leads to high project portfolio success, which consists of the five dimensions business success, economic success of the individual products, strategic fit, portfolio balance, and preparing for future. This can be achieved via different methods, including financial methods, bubble diagrams, and scoring models.

3.2.3 Evaluation Criteria

As described in paragraph 3.1, ideas or projects that flow through the product innovation process have to pass gates where they are evaluated. These gates consist of three components: deliverables, criteria, and outputs. Deliverables are the results of the activities during the preceding stage and are evaluated during the gate meeting on the basis of predefined criteria, which can be either should-meet or must-meet. Should-meet criteria are used for prioritising projects, must-meet criteria are designed to quickly filter out misfit projects. The output of a gate is a decision (Go/Kill/Hold/Recycle) along with an approved action plan for the next stage (Cooper, 2008). Since each stage consists of different actions, the criteria also differ for each gate. Hart, Hultink, Tzokas and Commandeur (2003) investigated these criteria via a survey among 166 managers from Dutch and UK companies that are developing and manufacturing industrial goods. They collected information on criteria that companies use at various evaluation gates in the innovation process. This resulted in a list of evaluation criteria that the companies used at each gate and a comparison between Dutch and UK companies. Later, in a different research team, the lists are merged to come to the overview as shown in table 3.2.

TABLE 3.2: USE OF EVALUATION CRITERIA AT EACH GATE (ADAPTED FROM TZOKAS ET AL., 2004)

NPD evaluation gates	Evaluation criteria																			
	Market-based							Financial-based				Product-based				Process-based			Intuition-based	
	Customer acceptance	Customer satisfaction	Sales objectives	Sales growth	Market share	Sales in units	Market potential	Break-even time	Profit objectives	IRR/ROI	Margin	Product performance	Quality	Product uniqueness	Technical feasibility	Stay within budget	Introduced in time	Time-to-market	Marketing chance	Intuition
Idea screening	49	33	33	27	29	32	**59**	10	26	9	29	43	29	**58**	**70**	12	17	23	32	**56**
Concept testing	**51**	38	14	4	6	17	32	7	11	8	13	44	33	26	**52**	14	16	14	21	23
Business analysis	31	23	**54**	43	44	**64**	**57**	33	**55**	43	**57**	25	20	27	29	22	25	31	42	20
Product testing	39	37	12	7	8	19	17	11	13	10	20	**67**	**66**	33	**63**	47	38	31	11	19
Test market	**70**	**64**	16	10	13	22	26	11	15	11	20	**70**	**64**	27	44	23	33	25	17	16
Post-launch, short term	**60**	**62**	49	41	38	**62**	34	21	46	22	**53**	45	42	27	8	12	34	20	22	15
Post-launch, long term	37	**56**	44	49	48	**55**	27	14	47	27	**52**	36	34	18	4	7	9	4	13	10

Where: ■ over 50% of the companies in the sample make use of the criterion at this gate.

As becomes clear from table 3.2, each gate has different evaluation criteria. For example, the idea screening gate assesses customer acceptance, market potential, product uniqueness, and technical feasibility. At this gate, the management wants to make sure that the ideas with the highest market attractiveness are chosen, which are at the same time feasible. Because it is difficult to have precise information at this gate, management has also to rely on intuition by making a decision. Table 3.2 shows clearly that the use of intuition-based criteria declines as the process proceeds (last column). After idea screening, the market potential is further assessed by taking the customer acceptance again into account in the concept-testing gate. Also, more than 50% of the companies evaluate the technical feasibility at this gate. If the idea receives a Go, it will undergo a detailed analysis, mainly financial, that will be evaluated in the business analysis gate (Tzokas et al., 2004). Here, management needs to decide whether the idea will be transferred the development portfolio where substantial resources are committed to the actual development of the product. The business analysis gate uses mainly financial and sales-based criteria, notable is that the product-based criteria are hardly used. In contrast, in the next gate, the product testing gate, almost only product-based criteria are used. This can be logically explained since the management needs to verify that the product has been developed according to the specifications, which was not possible to verify in the previous gate. In the test market gate, the product-based criteria are extended with some market-based criteria since the product has been made available to its potential customers to evaluate. In this way, the team can detect any problems and new information can be gathered to confirm the eventual product success. Lastly, in both the post-launch gates, customer satisfaction, sales in units, and the margin are taken into account. For the short term, the focus is mainly on customer acceptance and customer satisfaction, to detect and quickly solve any problems. For the long-term, management is more interested in the contribution of the product to profits and sales (Tzokas et al., 2004).

Instead of relating the criteria to the gates, the criteria can also be related to the strategy of the project or program. Griffin and Page (1996) investigated this among the PDMA members and found that different strategies result indeed in the use of different criteria. Customer acceptance is for example more important for radical products, and firms with a cost reduction strategy focus more on margin goals than on profit to lower the costs.

To come to a final list of commonly used evaluation criteria, the list of Hart et al. (2003) was complemented with the study by Griffin and Page (1996) and more recent studies by Schmidt, Sarangee, and Montoya (2009) and Henttonen, Ojanen, and Puumalainen (2015). The criteria were categorised into market, financial, and product criteria. Table 3.3 shows all the commonly used criteria, where the numbers after the criteria refer to the source of the criterion. Appendix C gives the descriptions of the criteria.

TABLE 3.3: COMMONLY USED EVALUATION CRITERIA FOR IDEAS OR PROJECTS

Market-based criteria	Financial-based criteria	Product-based criteria
Customer acceptance [1, 2, 3, 4]	Break-Even time [1, 2, 3, 4]	Product performance [1, 2, 3]
Customer satisfaction [1, 2, 3, 4]	Profit [1, 2, 3, 4]	Product quality [1, 2, 3]
Sales in units [1, 2, 3]	IRR [1, 2, 3, 4]	Time-to-market [1, 2, 4]
Market share [1, 2, 4]	ROI [1, 2, 3, 4]	Introduced in time [1, 2]
Revenue [1, 2, 4]	Margin [1, 2, 4]	Development costs [1, 4]
Sales growth [2, 3]	Stay within budget [2, 3]	Level of innovativeness [1, 4]
Market potential [2, 3]	NPV [3]	Technical feasibility [2, 3]
Portfolio fit [3]	Risk taking [4]	Competitive advantage [1]
Chance to be first to market [3]		Product uniqueness [2]
Market growth [3]		Potential for patents [3]
		Technical synergy [3]

Mentioned by: [1] Griffin and Page (1996), [2] Hart, et al. (2003), [3] Schmidt et al. (2009), [4] Henttonen et al. (2015)

These evaluation criteria are the input of the portfolio decisions and thus needs to be assessed on data accuracy. The overview showed that there are many different types of evaluation criteria which are both qualitative and quantitative. The assessment guide should be able to deal with all these types evaluation criteria.

Answer to literature review question 7:

"On what criteria are ideas or projects selected?"

Ideas or projects are selected on a wide range of evaluation criteria, which can be divided into market-based, financial-based, and product-based criteria. Table 3.3 gives an overview of commonly used criteria. The data underlying these criteria is that data that has to be assessed.

The current and previous paragraph examined the context of the current research, resulting in input for the development of an assessment guide. Now the context is examined, the next and last paragraph of the literature review will focus on the actual assessment of the accuracy of evaluation data.

3.3 DATA ACCURACY

The previous two paragraphs discussed the ideation phase and portfolio management, which are topics from the research area of new product development. Because no relevant literature on data accuracy was found in this area, the current paragraph aims to extract knowledge from the research area of information science. This was done via two literature review questions:

8. *"How is accuracy defined?"*
9. *"How can accuracy be measured?"*

The two questions above will be answered by the next four paragraphs. The first paragraph defines the construct of data accuracy in order to prevent ambiguity in the development of an assessment guide and introduces two approaches to measure accuracy: an objective and a subjective approach. The second and third paragraphs discuss these approaches in more detail. Lastly, since the actual measurement of accuracy is only one part of the to be developed assessment guide, the fourth paragraph discusses the whole process of assessing accuracy.

3.3.1 Introduction to Data Accuracy

Data accuracy is one of the many dimensions of the construct data quality. A commonly used definition of data quality was made by Wang and Strong (1996, pp. 6): "data that is fit for use by data consumers". Appendix D gives an overview of the commonly used data quality dimensions. From the dimensions, data accuracy can be considered as an all-encompassing dimension since early studies on data quality took only this dimension into account (Wang and Strong, 1996). Moreover, it is a common practice to use the term accuracy when referring to whether the data is correct, making this one of the key data quality dimensions (Lee, Pipino, Funk, and Wang (2006).

The dimension accuracy was defined by Wang and Strong (1996) as the extent to whether data is correct, reliable, and free of error. More recent articles defined accuracy more specific, namely as the extent to which the value of the data represents the true value of the attribute in the real world (Caballero, Serrano, and Piattini, 2014; Laranjeiro, Soydemir, and Bernardino, 2015). This definition suggests that the assessment of accuracy requires a test with the real-life object.

Answer to literature review question 8:

"How is accuracy defined?"

Initially, accuracy was defined as the extent to whether data is correct, reliable, and free of error. This shows the all-encompassing character of this data quality dimension. More recent, researchers defined accuracy as the extent to which the value of the data represents the true value of the attribute in the real world. The current research sticked to this more recent definition.

Although the definition of accuracy suggests the need for a comparison with the real-life object, there is also an alternative to this approach. This results in two ways to assess accuracy: via metrics and via surveys (Pipino, Lee, and Wang, 2002). Metrics are an objective approach of assessment and surveys are a subjective approach of assessment. The combination of these approaches leads to the best assessment (Pipino et al., 2002), but is not always possible due to the need for a comparison with the real-life object in the objective approach (Bovee, Srivastava, and Mak, 2003). This is especially the case for data in the ideation phase because, as discussed in paragraph 3.2, a lot of data in the ideation phase are forecasts of future conditions. However, to be complete, the next two paragraphs discuss both the objective and subjective approach for assessing data accuracy. The outcome of the assessment is a level of accuracy, which is in this study referred to as “accuracy information”.

3.3.1 Measuring Accuracy: The Objective Approach

In general, data accuracy dimensions are measured on a scale from 0 to 1 to represent the lowest to the highest accuracy, also called a simple ratio (Pepino, Lee, and Wang, 2002). The measurements that assess data accuracy dimensions are also known as assessment metrics (Blake and Mangiameli, 2011). The scale of 0 to 1 is caused by the way metrics are calculated; in most metrics, the number of undesirable records (or outcomes) is divided by the total amount of records. Subsequently, the simple ratio of accuracy can be calculated, where 1 means completely accurate, and 0 means completely inaccurate. This led to the following assessment metric for accuracy (Lee, Pipino, Funk, and Wang, 2006; Blake and Mangiameli, 2011):

$$Accuracy\ rating = 1 - \left(\frac{Number\ of\ undesirable\ records}{Total\ number\ of\ records}\right)$$

The context where the assessment metric is used defines what constitutes to the definition of an undesirable record. For example, in one case the deviation of a single character in a text string is allowed, in other circumstances, all the characters have to be correct.

3.3.2 Measuring Accuracy: The Subjective Approach

The subjective approach of data accuracy assessment is measuring accuracy via a survey among the data users or collectors (Pipino et al., 2002). The survey reflects the data accuracy dimensions that have to be measured in order to determine the level of data accuracy. To support organisations in the subjective approach of measuring data accuracy, a questionnaire was developed by Lee, Strong, Kahn, and Wang (2002). However, this questionnaire is not appropriate for the current study because it takes the overall construct of data quality in general into account, instead of focussing on the dimension accuracy.

To measure accuracy via the subjective approach, a similar questionnaire as the one by Lee et al. (2002) had to be developed to measure sub-dimensions of accuracy instead of measuring all data quality dimensions. A search in literature for sub-dimensions of accuracy led to the following list:

- **Believability.** Believability is defined as the extent to which data is regarded as true, correct, and credible (Neumann and Rolker, 2005; Huang, Stvilia, Jörgensen, and Bass, 2012; Schaal, Smyth, Mueller, and MacLean, 2012). The inclusion of "correct" in the definition shows the overlap with accuracy. The difference however with accuracy is that believability reflects an individual's assessment of the data instead of a comparison with the real-life object. Lee et al. (2002) described this as an individual's assessment of the credibility and comparison to a commonly accepted standard or previous experience. Other authors referred to this sub-dimension as credibility, however, argued that the source of the data has not to be taken into account (Bovee et al., 2013). The source is already taken into account in the sub-dimension reputation.

- **Reputation.** The sub-dimension reputation is directly linked to accuracy (Wang and Strong, 1996) and takes both the source and the content of the data into account. It can be defined as the extent to which data are trusted or highly regarded in terms of their content or source (Wang and Strong, 1996; Lee et al., 2002; Huang et al., 2012). In contrast to the sub-dimension believability takes the sub-dimension reputation not only the data itself into account.
- **Objectivity.** Objectivity is defined as the degree to which data are unbiased (unprejudiced) and impartial (Wang and Strong, 1996; Neumann and Rolker, 2000). Lee et al. (2002) extended this sub-dimension by also taking the collection into account. They defined it as the extent to which data is objectively collected, based on facts, and present an impartial view. Schaal et al (2012) stated that objectivity directly enhances accuracy.
- **Coherence.** The sub-dimension coherence is defined as the extent to which the data is focussed on one topic or one real-world object (Stvilia, Gasser, Twidale, and Smith, 2007; Schaal et al., 2012).
- **Consistency.** Although consistency is already a data quality dimension, it is also considered as a sub-dimension for accuracy. It is defined as the extent to which data is consistent with related other data (Prat and Madnick, 2008). This can be split into consistency over time and consistency over sources (Prat and Madnick, 2008; UNECE/HLG, 2014). Other authors took by consistency mainly the format and annotations of the data into account (Wang and Strong, 1996; Stvilia, 2007; Huang et al. 2012). However, this is mainly applicable for quantitative data and less applicable to the qualitative data in the ideation phase.
- **Complexity.** The sub-dimension complexity is defined as the degree of cognitive complexity of data relative to a particular activity, which can be measured by an index (Stvilia et al., 2007; Schaal et al., 2012). Complexity can also be defined as a lack of simplicity and uniformity in the data, taking the indicators "amount of structure" and "readability" into account (UNECE/HLG, 2014).

In addition to the list above, Clement (1999) provided empirical evidence for two other sub-dimensions: skills of the analyst and size of the company. Skills of the analyst are defined as the time in which an analyst is active in the concerning market. The more experience an analyst has in a particular market, the better forecasts he is able to make. However, this is already taken into account in the sub-dimensions reputation, since reputation takes the source of the data into account. The other sub-dimension, size of the company, is a constraint in the context of the ideation phase and is the same for every project in a portfolio which makes it not relevant to take into account.

The objective and subjective assessment approaches are only one element of the process of measuring accuracy. The complete process can be defined as an assessment guide, which will be discussed in the next paragraph.

3.3.3 Data Accuracy Assessment Guide

Besides metrics and sub-dimensions to measure accuracy, organisations also need a guide that that leads them through the process of developing an approach to measure accuracy: from data collection to presenting the accuracy information to decision makers. Several studies discussed a guide that partly covers this process (Woodall, Borek, and Parlikad, 2013). Woodall et al. (2013) conducted a meta-analysis on these studies and introduced an overall guide to build a data accuracy assessment approach. A comparison of the earlier established guides and methods led to a list of seven activities that they have in common. Woodall et al. (2013) referred to these activities as 'recommended' activities. The activities are listed and explained in the table below.

TABLE 3.4: RECOMMENDED ACTIVITIES IN ASSESSMENT APPROACH (ADAPTED FROM WOODALL ET AL. 2013)

	Activity	Definition of activity
1	Select data items	The process of selecting the relevant data values, attributes, tables, information systems, paper files etc. which will be subject to the assessment.
2	Select a place where data is to be measure	Select the place in the process where data is to be measured based on the objectives for measurement.
3	Identify reference data	The process of determining comparison data which can be used as input to the selected metrics.
4	Identify data accuracy dimensions	The process of identifying dimensions or using an existing model of data accuracy dimensions.
5	Identify data accuracy metrics	The process of identifying, developing or using an existing set of metrics.
6	Perform measurement	The process of obtaining measurements from an actual data set or by obtaining (subjective) opinions of the current state of data accuracy.
7	Conduct analysis of the results	The process of analysing the values from the DQ measurement(s).

Looking back at the literature review questions, the approach by Woodall et al. (2013) gives a partial answer to the question how accuracy can be measured. However, Woodall et al. (2013) did not provide instructions on how to execute the actual activities to implement accuracy assessment or, for example, what sub-dimensions or metrics to use in the ideation phase.

Answer to literature review question 9:

"How can accuracy be measured?"

Accuracy can be measured via objective and subjective approaches. Objective approaches use metrics to measure accuracy via a comparison of data values with the values of the real-life object. Subjective approaches use sub-dimensions that are measured via a survey among the data users or collectors. For the ideation phase, the subjective approach is most appropriate because a comparison with the real-life object is not possible. The process of measuring data accuracy can be formalised via an assessment guide, which defines the activities required to measure the data. The outcome of the data assessment is a level of accuracy, referred to in this study as "accuracy information".

This paragraph discussed the last topic of the literature background. The next paragraph concludes the literature background by explaining the contribution of the acquired knowledge to the development of an assessment guide.

3.4 CONCLUSION

The literature review presented in this chapter aimed to acquire knowledge on three topics: the ideation phase, portfolio management, and data accuracy. First, the literature on the ideation phase showed that organisations are guided by a product innovation process, which gives the opportunity to incorporate data assessment into this process leading to obtain a routine assessment of data accuracy. The literature regarding the ideation phase shows also that knowing the level of data accuracy can reduce fuzziness, which is one of the main challenges of the ideation phase. Secondly, the literature on portfolio management presented the main activity of portfolio management in the ideation phase: selecting the right ideas for further development. Accordingly, the assessment of data accuracy should contribute to this process, which can be, for example, by considering the level of accuracy as an additional criterion to the evaluation criteria discussed in the literature. Third and lastly, the literature on data accuracy gave some approaches on how to measure data accuracy. However, no literature was found that discusses data accuracy in the context of new product development or gives clear guidance in the activities exactly have to be executed to measure accuracy.

From the literature discussed in this chapter, a model (figure 3.3) can be derived that shows the potential role of data accuracy in the ideation phase. The model shows that decision makers can get the data accuracy information presented next to the project evaluation criteria. The project evaluation criteria are based on evaluation data (relation 1). The data accuracy information is based on sub-dimensions of accuracy (relation 3). These sub-dimensions, in turn, can be measured from the evaluation data (relation 2) by using a subjective approach.

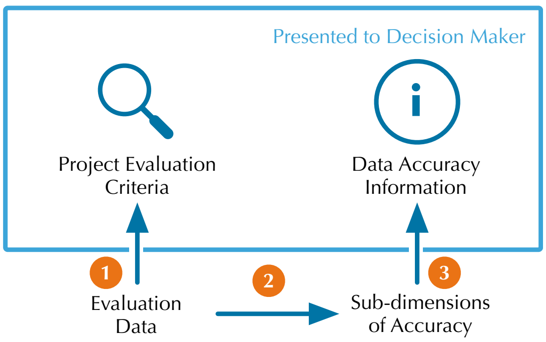

FIGURE 3.3: DATA ACCURACY ASSESSMENT IN THE IDEATION PHASE

In order to develop a guide that supports organisations by the implementation of data accuracy assessment in the ideation phase, some additional knowledge is required. This includes for example insights in the collection and storage of evaluation data, knowledge on what data accuracy information decision makers need (e.g. whether information about both low and high accuracy is relevant to show), and insights into the process of ideation portfolio management in order to define the moment of assessment. The next chapter aims to acquire this additional knowledge and validate the findings from the literature review via empirical research.

4 Empirical Research

Since it was not possible to extract all required knowledge for the development of an assessment guide from literature, additional knowledge had to be gained via an empirical research. As discussed in the research methodology, this was done via interviews at large organisations that perform portfolio management in new product development already for many years. Due to confidentiality reasons, the names of the organisations are not included. Besides the acquisition of additional insights, the empirical research also aimed to validate the findings regarding data accuracy in the context of new product development, because these are in the literature written in a more general context.

This chapter is structured similarly as the literature review. The next three paragraphs discuss findings regarding the ideation phase, portfolio management, and data accuracy. Every paragraph starts with the introduction of the empirical research questions that the paragraph aims to answer. When a question is answered, the answer is given in a blue box. The main contributions from the three topics are outlined in the conclusion of this chapter.

4.1 THE IDEATION PHASE

Since the context in which the assessment guide will be used is the ideation phase, the first topic of the interviews was the ideation phase. This part of the interviews aimed to answer the empirical research question listed and discussed below:

1. *"Do all organisations have an ideation phase and go-to-development gate?"*
2. *"How do organisations collect and store data in the ideation phase?"*

Because the current research focussed on the ideation phase, portfolio managers were asked if their organisation uses a product innovation process and if this process starts with an ideation phase. Subsequently, questions were asked regarding the collection and storage of data, since data accuracy should be implemented in this process.

4.1.1 The Product Innovation Process

During the interviews, a simple product innovation process was shown to the portfolio managers. The portfolio managers explained that their organisation also uses a product innovation process. However, the phases and gates are called differently by the organisations, and many organisations have another gate before the go-to-development gate. Accordingly, the ideation phase as defined in the literate background covers in some organisations more phases. An example is the division of the ideation phase into a phase responsible for market information and a phase responsible for financial information. Nevertheless, the characteristics of the ideation phase and go-to-development gate were recognised by all the portfolio managers, leading to the possibility to reflect their own process to the general definition and indicate their ideation phase and go-to-development gate. Lastly, during the interviews turned out that not all the organisation follow the formal processes always strictly, which sometimes leads to overlapping stages or skipping gates.

Using the findings above, the first empirical question can be answered as in the box below. The next paragraph examines the ideation phase further by looking at the data used in this phase.

Answer to empirical research question 1:

"Do all organisations have an ideation phase and go-to-development gate?"

All organisations included in the empirical research explained that they follow a structured new product development process, but they call the phases and gates different from discussed in the literature review. Moreover, some organisations split the ideation phase into more phases. However, portfolio managers were able to indicate their go-to-development gate and part of the process that they recognised as the ideation phase.

4.1.2 Data Use in the Ideation Phase

From the interviews appeared that none of the organisations has a structured collection of data in the ideation phase, with the exception of one company that assembles a dedicated team for the collection of data for radical new products. In all other cases, organisations collect data on a continuous basis by different people on which the portfolio managers lack overview. The storage of the data is also unstructured: in general, employees store the data on their own devices. Reasons mentioned for this are expected uncertainty of the data and the demand by collectors to explain the interpretation of the data. As a result, most of the portfolio managers mentioned the accessibility of obtained data as a problem in their organisation. Only just prior to the go-to-development meeting, the product owner or portfolio manager enters the conclusions of the collected data in an information system to make it accessible for other people in the organisation. Accordingly, the second empirical research question is answered in the box below. The next paragraph examines further how organisations deal with data in the ideation phase and how decisions are based on this data.

Answer to empirical research question 2:

"How do organisations collect and store data in the ideation phase?"

Both the collection and store of data is described by portfolio managers as unstructured. Portfolio managers explained that different people collect data, but an overview is often lacking. Moreover, it was mentioned that data is stored locally on personal devices until to the go-to-development meeting when they are merged into an information system.

4.2 PORTFOLIO MANAGEMENT

Another topic regarding the context of the assessment guide is portfolio management. This part of the interviews aimed to answer the next three empirical research questions.

3. *"How do organisations take portfolio decisions?"*
4. *"What data do organisation need to take portfolio decisions?"*
5. *"What are the sources of the data organisations use to take portfolio decisions?"*

Because the data assessment guide aims to improve portfolio decision making, the guide should fit in the current practices of portfolio management. Particularly, it should be able to deal with the data on which portfolio decisions are based, because of this data portfolio managers want to know the level of accuracy. Since the theoretical background already provided the types and sources of data, the empirical research has as goal to validate and extend these findings. Accordingly, the next two paragraphs answer the empirical research questions above.

4.2.1 Portfolio Management in the Ideation Phase

By asking the interviewees on how portfolio management is performed in their organisation, it turned out that, although portfolio management takes place during the product innovation process, there also exists another process: the process of data collection, storage, processing and presentation. Portfolio managers referred to this as preparation for the go-to-development gate at the end of the ideation phase, where the actual portfolio management is performed. In general, portfolio decisions are taken by the highest hierarchical level of an organisation, mostly referred to as the board of directors. These decisions, which includes the gate decision to continue, stop, or recycle a project, are taken every three, six, or twelve months. Interviewees referred to these decisions as strategic decisions. One of the interviewed companies assembles a formal team to prepare the portfolio decisions, but only in case of radically new products. In other organisations, the preparation is done by the product owner or project manager, who has as main task to manage the people at different departments in the collection of the data and check if all data is entered in the information system. This information system draws graphs on which the decision makers based their decisions.

Answer to empirical research question 3:

"How do organisations take portfolio decisions?"

Portfolio decisions are in general taken by the board of directors of an organisation every three, six, or twelve months. The decisions are prepared by a product owner, who leads the people that collect the data and subsequently check if all data is entered in the information system. The information system is used during portfolio meetings since it displays the graphs to base the decisions on.

4.2.2 Data Use in Portfolio Management

By introducing the topic of data, all the interviewees mentioned that most of the data on which the decisions are based is qualitative: descriptions or ratings. This is in line with the findings of the literature review which accordingly focussed on the subjective assessment of the data since objective assessment is only valid for quantitative data. Also in accordance with the literature review, organisations collect data to evaluate projects on different evaluation criteria. The criteria are in accordance with the literature review (table 4.1) and are, also in accordance with the literature background, mainly market- and financial based. Besides these categories of criteria, portfolio managers mentioned strategic criteria as an important third group, by which they meant a check if the idea or project fits with the organisation's strategy. Although the literature background described a couple of strategic evaluation criteria, the fit with the organisation's strategy is not included.

Answer to empirical research question 4:

"What data do organisations need to take portfolio decisions?"

In accordance with the literature, organisations use mainly the market or financial based criteria from table 3.1 in the literature background. Portfolio managers argue that data is mainly qualitative: descriptions or ratings, which is in accordance to the literature background. In addition to the literature background, portfolio managers mentioned that strategic fit is also an important evaluation criterion.

As already mentioned in the previous paragraph, data is collected by people at different departments in the organisation. From the empirical research appeared that not all portfolio managers are aware of the underlying sources of the collected data. The portfolio managers that knew the sources, mentioned both internal sources and external sources. Examples of internal sources are historical data on sales and production, insights from professionals in a particular market and internally developed market reports. Mentioned external sources are market data, customer data, and data regarding competitors. These findings answer the empirical research question below regarding the sources of data. The next paragraph collects knowledge on the actual assessment of data.

Answer to empirical research question 5:

"What are the sources of data organisations use to take portfolio decisions?"

Data that organisations use in portfolio decisions come both from internal and external sources of the organisation. Internal sources are for example sales and production data, external sources are market reports or competitor data.

4.3 DATA ACCURACY

Lastly, the empirical research aimed to acquire knowledge on data accuracy. Accordingly, this paragraph aims to answer the empirical research questions listed and discussed below:

6. *"Do organisations currently take the accuracy of data into account?"*
7. *"What sub-dimensions of accuracy can portfolio managers think of?"*
8. *"What data accuracy information do organisations need at what moment?"*
9. *"What is the best moment to measure the accuracy of data?"*

First, portfolio managers were asked how they currently take the accuracy of data into account, to include these actions possibly in the to be developed assessment guide. Because the literature review concluded that the assessment has to be done via a subjective approach that relies on sub-dimensions of accuracy, interviewees were asked if they can identify sub-dimensions. Lastly, the empirical research needed to collect practical information on what accuracy data portfolio managers need, when they need it, and what the best moment is to assess the accuracy of data. The empirical-research questions above are answered in the next three paragraphs: first, the current practices regarding data assessment are discussed, secondly, the list of sub-dimensions is attempted to extend, and thirdly, practical information of the assessment is collected.

4.3.1 Current Practises Regarding Data Accuracy

In general, the portfolio managers described data accuracy as correctness and the ability to rely on the data, which is in accordance with the literature review. Some organisations already have some (informal) practices in place to improve the accuracy of data. One of the organisations, for example, indicated that they actively try to higher the data accuracy via triangulation of sources.

Of the six interviewed organisations, two organisations explained that they perform a quick accuracy check of the data. One of these organisations achieves this by classifying the amount of guessing in a calculation. The collector of the data documents whether the estimation is a wild guess, an educated guess, or a pretty certain estimation. The other organisation that performs an accuracy check via a more structured approach. This organisation agreed with the collectors of the data that by entering the data into the portfolio management software, estimations have to be made of the accuracy. These estimations are made via a single overall rating for data accuracy: low accuracy, medium accuracy, or high accuracy. This approach results in the involvement of data accuracy information during gate meetings, which is exactly what other organisations also want to achieve. Although this organisation uses the approach already for several years, they still struggle with the problem that the assessment is not reliable. This because the assessment depends highly on the engineer that collects the data and thus makes the estimation of the accuracy. According to the literature background, this can be solved by using sub-dimensions of accuracy, however, the concerning organisation had no insights in this knowledge. Another problem the organisation mentioned was that they are only able to check the data on project level: the whole idea or project receives, for example, the label "low data accuracy" in case some of the data has a low level of accuracy. This makes it hard to track data with a low level of accuracy. Accordingly, the assessment should be performed and stored on the level of evaluation criteria (for example, only the market size receives a "low data accuracy" label). Another interesting finding at this organisation is that the interviewed portfolio managers mentioned that low data accuracy serves a trigger for data collectors to collect more data or take actions to validate the data. This confirmed the earlier discussed possibility to take interventions following from low data accuracy.

The other companies, that don't assess their data accuracy, mentioned that they take data accuracy indirectly into account by asking questions related to the source of the data. These portfolio managers mentioned that there are often discussions about the accuracy of data, but this results rarely in a conclusion regarding the level of data accuracy. By using these finding of the interviews, the sixth empirical research question can be answered (next page). As a result from the need to measure accuracy as reliable as possible, the next paragraph discusses sub-dimensions of accuracy.

Answer to empirical research question 6:

"Do organisations currently take the accuracy of data into account?"

In the empirical research, six organisations were examined. All the organisations indicated that they take the accuracy of data into account, however, only one organisation use the accuracy of data in their portfolio decisions. This organisation implemented an approach to assess the accuracy of evaluation data in their ideation phase, but struggle with the reliability of the assessment and perform the assessment only on the project (or idea) level, which makes it harder to perform actions on a low data accuracy than when the assessment is performed on the level of evaluation criteria.

4.3.2 Sub-dimensions of Accuracy

An extensive search in literature for sub-dimensions of accuracy led to a list of six sub-dimensions. This list was aimed to extend and validate via the empirical research. Accordingly, the interviewees were first asked to mention sub-dimensions themselves. Hereafter, the list of sub-dimensions was shown to the interviewees to discover if they could think of additional sub-dimensions of accuracy. Accordingly, interviewees mentioned the sub-dimension time frame and uncertainties in the calculation. By time frame, the interviewees meant that some data is only accurate till a particular moment in time. After this moment, the accuracy of the data decreases. However, because this moment is often unknown and not all data has this turning point, the indicator is not included in the final list of sub-dimensions. By uncertainties in the calculation, the interviewees meant that the more uncertainties or assumptions a calculation or reasoning has, the lower the data accuracy becomes. This is a combination of the from literature derived sub-dimensions objectivity and reputation and needs therefore not to be included in the final list of sub-dimensions. Although no additional sub-dimension were discovered for the assessment guide, this topic in the empirical research was still valuable since it confirmed the findings from the literature.

Answer to empirical research question 7:

"What sub-dimensions of accuracy can portfolio managers think of?"

Portfolio managers agreed with the list of sub-dimensions discussed in the literature background: believability, reputation, objectivity, coherence, consistency and complexity. Besides these six sub-dimensions, portfolio managers also mentioned two additional sub-dimensions that overlap with the ones from literature. This confirms that the six sub-dimensions cover the whole dimension of accuracy.

4.3.2 Assessing Data Accuracy

Lastly, some practical information was collected regarding the measuring of accuracy. This led to the conclusion that portfolio managers are more eager to be informed when data has a low accuracy than when data has a high accuracy. Portfolio managers even mentioned that they want to receive a warning when data has a low accuracy, which gives them the possibility to act on a low accuracy. However, at portfolio decisions, both high and low levels of data accuracy are important to take into account, preferably linked to a particular evaluation criterion. Lastly, portfolio managers indicated that accuracy information becomes more important as the innovation process proceeds. The findings led to the answer of the eighth empirical research question, which is presented below.

Answer to empirical research question 8:

"What data accuracy information do organisations need at what moment?"

The empirical research showed that during the preparation of the portfolio decisions, portfolio managers are most eager to know what evaluation data has a low accuracy, which gives the portfolio managers the possibility to perform correcting actions on it. During the portfolio decision itself, both high and low levels of accuracy are relevant to take into account to compare projects (or ideas) with each other.

The last practical question of the empirical research concerns the moment of assessment, in order to know when the accuracy assessment should be executed. All the interviewees indicated that, according to their experience, it would be most convenient to assess the data accuracy by entering the data into the system because the data needs to be assessed by the collector of the data, which also enters the data into the system. Moreover, this moment is close to the collection of the data, resulting in the availability of knowledge on, for example, the source of the data. This moment of data measurement is in line with the description above of the organisation that already assesses the accuracy of data, which also performs the measurement at the moment when the data was entered into the system.

Answer to empirical research question 9:

"What is the best moment to measure the accuracy of data?"

The measurement of accuracy can best be performed when the data is entered into the system for two reasons. First, because this data is entered by the collector of the data and the collector also have to measure the accuracy. Secondly, because this moment is close to the collection of the data, leading to the availability of knowledge on, for example, the source of the data.

This paragraph discussed the last topic of the empirical research. The next paragraph concludes the empirical research by explaining the contribution of the acquired knowledge to the development of an assessment guide.

4.4 CONCLUSION

The empirical research covered three topics: the ideation phase, portfolio management, and data accuracy. First, empirical research on the ideation phase confirmed that organisations are guided by a product innovation process, which gives the opportunity to incorporate data assessment into this process. However, the empirical research showed that every organisation uses a different product innovation process and the collection and storage of data is very unstructured in the ideation phase. Secondly, research on portfolio management led to the discovery of the process from data collection to portfolio decisions making (figure 4.1). In this process, mainly qualitative data is used. This confirmed the need for a subjective approach. The process also confirmed the finding from the literature that portfolio managers use a wide variety of sources for the data on which they base their portfolio decisions, resulting in the requirement that the assessment approach should be able to deal with all these different sources. Third and lastly, empirical research on data accuracy resulted in insights into the experiences of an organisation that already assessed data accuracy, leading to the confirmation that sub-dimensions should be used in the assessment. The empirical research on data accuracy also confirmed the list of six sub-dimensions extracted from the literature. Lastly, interviewees explained that they want to be informed when data has a low accuracy in the ideation phase and that during portfolio decisions, both high and low levels of data accuracy are important to take into account, linked to a particular evaluation criterion.

Besides the findings summarised above, the empirical research also discovered a process that portfolio managers follow in the preparation of a portfolio decision, as already introduced in paragraph 4.2. This process was discovered because several portfolio managers indicated that the portfolio management process was not part of the product innovation process.

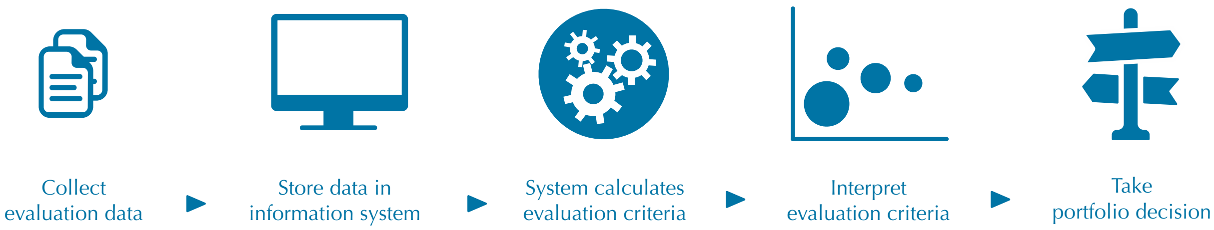

FIGURE 4.1: PROCESS FROM DATA TO DECISION MAKING

The figure above shows the earlier mentioned process from data collection to decision-making, extracted from the empirical research. This process turned out to be the same for all interviewed organisations and also familiar to Bicore. In general, the data collectors store the data in the information system. The information system processes the data and calculates predefined evaluation criteria from it in order to make the ideas or projects comparable to each other. The evaluation criteria are cumulated in graphs, which the decision makers interpret to take a decision. In contrast to the product innovation process, organisations have not documented this process. However, because this process is the same for all organisations, the moment of assessment can be defined on basis of this process (for example, by storing the data). Subsequently, this moment can be translated to the moment in the ideation phase of the individual organisation.

To conclude, the empirical research provided relevant insights in how organisations deal with data and data accuracy in the ideation phase. This turned out to be more or less the same for all organisations. As a result, already during the first interviews, the number of new findings decreased at every subsequent interview. This tendency continued during the other interviews which is a sign of saturation, leading to the conclusion that enough interviews were conducted for the purpose of this study (Morse, 1995). The interviewees mentioned a clear need for a guide that supports them in the implementation of data accuracy assessment in the ideation phase, which is exactly what the solution of the current research aims to achieve. The next chapter translates the knowledge acquired during the empirical research and literature review via the sub-research questions to design principles, on which the solution will be developed.

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5 Design Principles and Requirements

This chapter defines the design principles and design requirements for the solution design. Since these will be derived from the answers to the sub-research questions, this chapter first combines the knowledge from the literature review and the empirical research to answers to the sub-research questions. The structure of this chapter follows the sub-research questions: every paragraph answers one of the sub-research questions and subsequently derives design principles from the answer. Lastly, design requirements are defined and the chapter is concluded by mapping the design principles to the process from data to decision making.

5.1 THE IDEATION PHASE

The first sub-research question aimed to collect knowledge regarding the context of the assessment guide and was defined as follow:

"What are goals and challenges of the ideation phase?"

This question was answered by literature review questions 1, 2, 3, and the first empirical research question. The literature review on the ideation phase showed that organisations in new product development are guided by a product innovation process in what activities have to be executed at what moment (Kahn, 2002; Crawford and Di Benedetto, 2012; Cooper, 2014). However, this process differs per organisation. By comparing the ideation phase with the subsequent development phase, it became clear that the ideation phase is less structured and has more uncertainties (Koen et al., 2002). The goal of the ideation phase is to identify opportunities and ideas, evaluate and select ideas, and lastly bundle these ideas into proposals for new projects (Heising, 2012). In the literature, two main challenges of the ideation phase are described: reducing fuzziness and accelerating the ideation phase (Chang et al., 2007; Kim and Wilemon, 2010). These challenges are related to each other because methods that reduce fuzziness also reduce the lead time of the ideation phase.

The empirical research showed that all the interviewed organisations follow a structured product innovation process, but the phases and gates are called different from discussed in the literature review. The use of a structured product innovation process gives the opportunity to incorporate the assessment of data accuracy into this process. This will likely lead to a routine assessment of the data. However, because the product innovation process differs per organisations, organisations have to be able to implement the data accuracy assessment in the process themselves. This results in the need for a guide that organisations can use for the implementation, which is translated to the first design principle, the intervention printed **bold**.

TABLE 5.1: DESIGN PRINCIPLE 1

	Principle	Based on*
1	Organisations that want to assess data accuracy should **use a guide that supports them in the implementation of accuracy assessment** in their portfolio management practices in the ideation phase. This is expected to result in a more routine assessment, leading to better estimation of accuracy to take into account in portfolio decisions.	LRQ 1, LRQ 2, LRQ 3, ERQ1

*LRQ = Literature review question, ERQ = Empirical Review Question

This principle focusses on portfolio management in the ideation phase. As discussed earlier, portfolio management in the ideation phase requires data. This will be examined further by the next sub-research question.

5.2 DATA USE IN THE IDEATION PHASE

The second sub-research question concerned the collection and usage of data in the ideation phase and is defined as follow:

"How do organisations collect and store data in the ideation phase?"

This question was answered by literature review question 4 and empirical research question 2. In order to examine how organisations collect and store data, first, the types and sources of data organisations use were extracted from the literature. In total nine types of data were found, over three categories: internally developed data, externally obtained data, and externally obtained data that that is internally developed (Keylly and Story, 2000; Zahay et al., 2011). The categories give some information on the source of the data, which is expected to differ between incremental and radical products (Brentani and Reid, 2012). For incremental innovations, opportunities are from within the organisation directed to individuals to gather more data in the environment. For radical innovations, data is received from the environment by individuals and brought into the organisation. However, in the literature, no information was found regarding the exact sources, collection, and storage of the data, which therefore needed empirical research.

The empirical research showed that both the collection and storage of data in the ideation phase is unstructured. Interviewed portfolio managers described that data is collected by different people in different departments, which differs per project (or idea) and regularly lacks overview. Moreover, data is stored locally on personal devices until to the go-to-development meeting when they are merged into an information system.

The unstructured collection and storage of data could be a problem for the assessment of data accuracy. This could be solved by structuring the collection and storage of data during the implementation of data accuracy assessment; for example by defining moments in the ideation phase when data has to be entered into the information system and when the data has to be assessed. The design principle below describes this need to structure the data collection and storage (intervention printed in **bold**).

TABLE 5.2: DESIGN PRINCIPLE 2

	Principle	Based on*
2	Organisations that want to assess data accuracy should **structure their process of data collection and storage by defining moments** in their ideation phase when data has to be collected or stored to the system. This is expected to result in a more routinely assessment, leading to better estimation of accuracy to take into account in portfolio decisions.	LRQ 4, ERQ 2

*LRQ = Literature review question, ERQ = Empirical Review Question

As already mentioned, the data discussed in this paragraph serves as input for portfolio decisions. In order to take the purpose and process of portfolio management into account in the development of an assessment guide, the next paragraph discusses portfolio management.

5.3 PORTFOLIO MANAGEMENT

The third sub-research question aimed to collect knowledge on portfolio management in the ideation phase:

"What is the main purpose of portfolio management in the ideation phase?"

This question was answered by literature review questions 5 and 6, and empirical research question 3. The literature discusses that decision making in the ideation phase entails selecting the right ideas for further development and can be divided into formal and informal approaches (Holahan et al., 2014; Eling et al., 2016). Consistent use of formal processes for both incremental and radical ideas leads to the highest firm's idea success rate (Eling et al., 2016), which can be explained by the importance of adopting a portfolio view during the ideation phase (Kock, Heising, and Gemünden, 2015). Adopting a portfolio view implies taking the contribution of an idea to the firm's NPD portfolio into account, besides the advantages of the individual projects.

The empirical research showed that portfolio decisions as described above are taken by the board of directors of an organisation every three, six, or twelve months. Only one of the interviewed organisations assembles a formal team to prepare the portfolio decisions. This confirms the in the previous paragraph discussed finding of unstructured data collection. However, after the collection, all organisations have the same process in place to prepare portfolio decisions: (1) the data is entered into the information system by the data collector, (2) the information system processes the data and calculates predefined evaluation criteria from it that are cumulated in graphs, (3) the decision makers interpret these graphs, and (4) a decision is taken based on the graphs. Although none of the organisations documented or formalised this process, it gives the opportunity to define the moment of assessment based on this process. Accordingly, the moment can be translated to the ideation phase of the structured product innovation process of the individual organisation. This results in an alignment of the process that prepares the portfolio decisions and the product innovation process. This was translated to the third design principle. Also here the intervention is printed in **bold**.

TABLE 5.3: DESIGN PRINCIPLE 3

	Principle	Based on*
3	Organisations that want to assess data accuracy should **align the process that supports portfolio management with their process of the ideation phase.** This is expected to result in more structured collection and storage of data, leading to better estimation of accuracy to take into account in portfolio decisions.	LRQ 5, LRQ 6, ERQ 3

*LRQ = Literature review question, ERQ = Empirical Review Question

As appears from the described process that prepares portfolio decisions, portfolio decisions require data. In the answer to the second sub-research question, already some categories and types of data in the ideation phase are mentioned. The next paragraph examines this further by defining what data is exactly needed for portfolio management and how this might influence the assessment of data.

5.4 DATA USE IN PORTFOLIO MANAGEMENT

The fourth sub-research question examined what data organisations need to perform portfolio management:

"What data is required to perform portfolio management in the ideation phase?"

This question was answered by literature review question 7 and empirical research questions 4 and 5. The literature review showed that ideas (or projects) are selected on a wide range of evaluation criteria. These criteria can be subdivided into market-based, financial-based, and product-based criteria. Table 3.3 in the literature background gives an overview of commonly used evaluation criteria. Since this is the data on which portfolio decisions are based (Hart et al., 2003), this is the data of which decision makers want to know the accuracy. As appears from the answer to the second sub-question, nine types of data are known in the literature (Zahay et al., 2011). Because portfolio managers want to compare the accuracy of this data, all data has to be assessed on the same criteria.

The evaluation criteria listed in the literature review were confirmed by the empirical research. The empirical research also confirmed that mainly qualitative data is used to take portfolio decisions at the end of the ideation phase. Lastly, the empirical research confirmed that portfolio managers use a wide variety of sources for data to base their portfolio decisions on. These findings have to be taken into account by making the data accuracy assessment generic for all types and the sources of data. This because the types and sources of data can vary between projects, but the outcome of the assessment should be comparable between evaluation data and sources. This led to the definition of the design principle below, the intervention printed **bold**.

TABLE 5.4: DESIGN PRINCIPLE 4

	Principle	Based on*
4	Organisations that want to assess data accuracy should **be able to use the same assessment approach for all data because the outcome of the assessment should be comparable.** Accordingly, the outcome will be comparable regardless the type or source of data, leading to valuable estimations of accuracy to take into account in portfolio decisions.	LRQ 7, ERQ 4, ERQ 5

*LRQ = Literature review question, ERQ = Empirical Review Question

This paragraph answered the fourth sub-research question by examining what data is needed for portfolio management, concluding that there is a wide variation in the data and sources the approach has to be able to assess. Since portfolio managers want to know the level of accuracy of this data, the next paragraph defines what accuracy is and how organisations take it currently into account.

5.5 DATA ACCURACY

The fifth research question aimed to collect general knowledge on the topic of data accuracy by defining data accuracy and examining how organisations currently take data accuracy into account. This led to the following sub-research question:

"How is data accuracy defined and currently taken into account by organisations?"

This question was answered by literature review question 8 and empirical research question 6. A definition for the construct of accuracy was synthesised from literature to prevent ambiguity in the development of the assessment guide. The current research sticked to the definition of accuracy as the extent to which the value of the data represents the true value of the attribute in the real world (Caballero, Serrano, and Piattini, 2014; Laranjeiro et al., 2015). This definition shows that the assessment of accuracy requires a test with the real-life object, which will be discussed later.

The empirical research regarding this sub-research question aimed to collect knowledge on how organisations currently deal with data accuracy. All interviewed portfolio managers mentioned that they regularly conduct discussions on the accuracy of data but that they lack insights in how to assess accuracy. However, one of the examined organisations uses a formal approach to take the level of data accuracy into account by taking portfolio decisions. This led to some insights into experiences on the assessment of data accuracy. The concerning portfolio manager explained that the main problem his organisation faces is that the determined level of accuracy depended highly on the estimation of the data collector, leading to an unreliable assessment. The literature background already discussed that the reliability of assessment can be improved by using sub-dimensions of accuracy. Accordingly, sub-dimensions have to be used by the assessment guide which led to the next design principle, the intervention printed **bold**.

TABLE 5.5: DESIGN PRINCIPLE 5

	Principle	Based on*
5	Organisations that want to assess data accuracy should **use the following sub-dimensions of accuracy: believability, coherence, complexity, consistency, objectivity, and reputation.** This is expected to lead to a better estimation of accuracy, which is more valuable to take into account in portfolio decisions.	LRQ 8, ERQ 6

*LRQ = Literature review question, ERQ = Empirical Review Question

Now accuracy is defined, organisations can be asked what accuracy information they need in order to take this into account in the assessment of accuracy.

5.6 DESIRABLE DATA ACCURACY INFORMATION

The sixth research question focussed on a practical aspect of the assessment guide; the data accuracy information decision makers need. Accordingly, the next sub-research question was defined:

"What data accuracy information do organisations need in the ideation phase?"

In the literature review on portfolio management, it was discussed that the level of data accuracy should be presented together with the evaluation criteria on which decision makers base the portfolio decisions. Besides this finding, no other insights were found in the literature regarding what data accuracy information decision makers need. Accordingly, the rest of the question above had to be answered by empirical research. Following the eighth empirical research question, portfolio managers were asked what data accuracy information they need at which moment. This led to the conclusion that the desired data accuracy information depends on the moment in the process. During the collection of data, portfolio managers are most eager to receive a message in case of low data accuracy, which gives them the possibility to act on a low level of accuracy. This leads to the sixth design principle, the intervention printed **bold**.

TABLE 5.6: DESIGN PRINCIPLES 6

	Principle	Based on*
6	Organisations that want to use data accuracy information in portfolio decisions, should **receive a warning during the preparation of the portfolio decision in case data has a low data accuracy**. Accordingly, actions can be taken to improve the accuracy of data, leading to a better decision outcome.	ERQ 8

Although the empirical research showed that portfolio managers consider a level of low data accuracy as most important information, during portfolio decisions, information concerning both high and low accuracy are important to know because this gives the opportunity to compare projects. However, the empirical research showed that portfolio managers want to compare the projects on the data accuracy of evaluation criteria, not on a merged level of data accuracy for a project. This resulted in the design principle that data accuracy information should be presented together with the evaluation criteria on which decision makers base their decision. This led to the seventh design principle, the intervention printed **bold**.

TABLE 5.7: DESIGN PRINCIPLE 7

	Principle	Based on*
7	Organisations that want to use data accuracy information in portfolio decisions, should be **presented with the data accuracy information next to the evaluation criteria.** Accordingly, comparisons can be made between projects and evaluation criteria, leading to better decisions.	LRQ 6, ERQ8

*LRQ = Literature review question, ERQ = Empirical Review Question

The principles above describe what data accuracy information organisation need. The next paragraph takes this into account by defining how data accuracy should be assessed.

5.7 ASSESSMENT OF DATA ACCURACY

Lastly, the actual assessment of data accuracy is researched, leading to the seventh sub-research question:

"How can data accuracy be assessed in the ideation phase?"

This question is answered by literature review question 9 and empirical research questions 7 and 9. A review of the literature on data accuracy assessment led to the finding that data accuracy can be assessed via an objective approach and via a subjective approach (Pipino et al., 2002). However, objective assessment is not always possible due to the need for comparison with the real-life object (Bovee et al., 2003). Unfortunately, this applies to data in the ideation phase since most data in the ideation phase are forecasts of future conditions (Tzokas et al., 2004) which makes a comparison with the real-life object not possible. As a result, the accuracy assessment guide for data in the ideation phase should use a subjective approach to assess data. The subjective approach determines the level of accuracy via sub-dimensions, that are measured via a survey among data users of collectors (Lee et al., 2002). To operationalise this subjective approach, six sub-dimensions of accuracy are extracted from literature: believability, coherence, complexity, consistency, objectivity, and reputation. These six sub-dimensions are confirmed by the empirical research. Although some interviewed portfolio managers used other names for the sub-dimensions, the definitions were comparable. Design principle 5 already mentions the sub-dimensions. The use of a subjective approach to assess accuracy is taken into account in design principle 8, the intervention printed **bold**.

TABLE 5.8: DESIGN PRINCIPLE 8

	Principle	Based on*
8	Organisations that want to assess data accuracy should **use a subjective approach to measure data accuracy in the ideation phase.** This is expected to lead to a better estimation of accuracy, which is more valuable to take into account in portfolio decisions.	LRQ 9, ERQ 4

*LRQ = Literature review question, ERQ = Empirical Review Question

The second and last finding from the empirical research regarding the assessment of data accuracy includes the moment of assessment. All portfolio managers indicated that data has to be assessed at the moment it is entered into the system. This because that moment is as close as possible to the collection of the data, resulting in the availability of knowledge on, for example, the source of the data. Since the use of sub-dimensions in the accuracy is already discussed in design principle 5, the findings above led to two additional sub-dimensions. First, as is concluded from the literature, organisations should use a subjective approach to measure data accuracy and secondly, the assessment should take place at the moment when data is added to the information system. The table below shows this principle, the intervention printed **bold**.

TABLE 5.9: DESIGN PRINCIPLE 9

	Principle	Based on*
9	Organisations that want to assess data accuracy should **assess the accuracy of data at the moment the data is entered into the information system.** This is expected to lead to a better estimation of accuracy, which is more valuable to take into account in portfolio decisions.	ERQ 7

*LRQ = Literature review question, ERQ = Empirical Review Question

This paragraph discussed the actual assessment of data accuracy, concluding that organisations should use a subjective approach and assess the data at the moment it is entered into the information system. Following the research methodology of the current study, besides design principles, also requirements have to be defined. These will be defined in the next and concluding paragraph of this chapter.

5.8 DESIGN REQUIREMENTS

The design principles in the paragraphs above already provided some guidance to the development of the assessment guide. Besides these design principles, the development was also guided by design requirements, which are conditions that the solution has to meet (van Aken et al., 2012). The design requirements were derived from the interviews because the interviewed portfolio managers are the potential users of the assessment guide. In total, four design principles were derived, which are discussed below.

First, since this will be the essence of the assessment guide, organisations should be guided by the assessment guide in the implementation of an approach to assess data accuracy as reliable as possible. This means that the perceptions of the data collector that assesses the data should have a minimum influence on the outcome of the assessment, leading to the possibility to compare assessments by different collectors. Secondly, in order to make the assessment guide effective, it should be unambiguous and user-friendly for portfolio managers to prevent an incorrect implementation. Thirdly, as already discussed in the paragraphs above, the assessment guide should be applicable to all the types of data that exist in the ideation phase. Fourth and last, the assessment guide should be understandable by all stakeholders of the data accuracy assessment, which should lead to a high level of support and better use within the organisation. The four design requirements are listed below.

1. The design should guide the organisation in the development of a custom-built data accuracy assessment approach that assesses data accuracy as reliable as possible.
2. The design should be unambiguous and user-friendly for portfolio managers.
3. The design should be applicable to all types of data, both qualitative and quantitative.
4. The design should be understood by all the stakeholders of the assessment guide, leading to a high support level within the organisation and easier implementation.

5.9 CONCLUSION

As discussed in the methodology, the current research followed a science-based design approach. This chapter defined two important elements of this approach: design principles and design requirements. These elements are the input for the design of the solution, which will be discussed in the next chapter.

The design requirements were derived from empirical research, resulting in criteria the solution must meet. The design principles were derived both from answers to the literature review questions and answers to the empirical research questions. This led to a total of nine design principles. From these design principles, seven principles define specific actions for the assessment guide. The other two principles describe the overall goal of the guide (principle 1) and the recommendation that organisation should align the preparation of portfolio decisions with the product innovation process (principle 3).

The other design principles (design principle 2 and 4 to 9) can be mapped to the process from data collection to decision making to give an overview of the principles. This led to the figure below. The next chapter discusses how the principles and earlier mentioned requirements will be taken into account in the design of the solution.

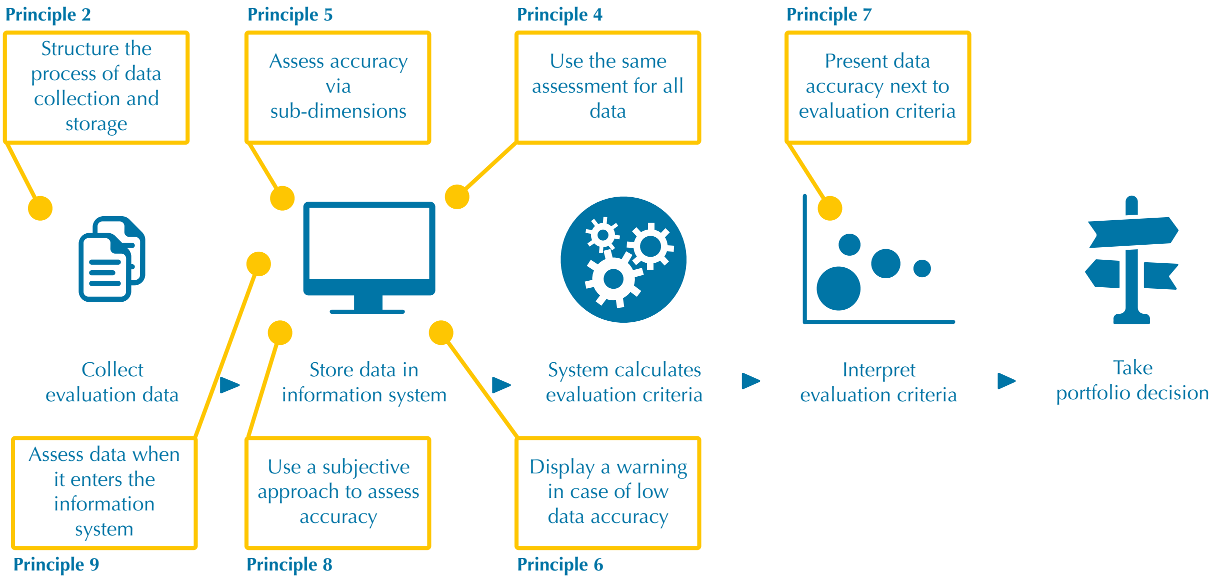

FIGURE 5.1: DESIGN PRINCIPLES IN THE PROCESS FROM DATA TO DECISION MAKING

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6 Solution Design

This chapter describes the design of the solution. As discussed in the introduction, the current research is initiated by Bicore to acquire knowledge in the assessment of data accuracy in the ideation phase. Bicore aims to apply this knowledge in their portfolio management software they develop for their clients. Accordingly, this chapter designs a guide to implement data accuracy assessment. This guide can be used both by Bicore and other organisations.

The chapter is structured as follows. First, the next paragraph describes how the design principles and design requirements are translated to a solution. Secondly, the solution is described in more detail. Lastly, the solution is verified via additional interviews.

6.1 DESIGN OF THE ACCURACY ASSESSMENT GUIDE

The goal of the assessment guide is described by the first design principle: guiding organisations in the implementation of data accuracy assessment. This guide consists of several actions that need to be defined in the context of the ideation phase. The research by Woodall et al. (2013) already presented a list of recommended activities. Although this list is defined in a different context than the ideation phase, it served as a starting point for the solution of the current research: a data accuracy assessment guide.

From this starting point, the assessment guide (figure 6.1) was designed via several iterations to translate the design principles to activities in the guide. In this process, also knowledge of Bicore is used as a first validation to make sure the guide fits the context. Later, the solution was validated at four different organisations to make it generic for other organisations in the field of new product development. The next three paragraphs explain how the design principles were translated into the activities of the guide.

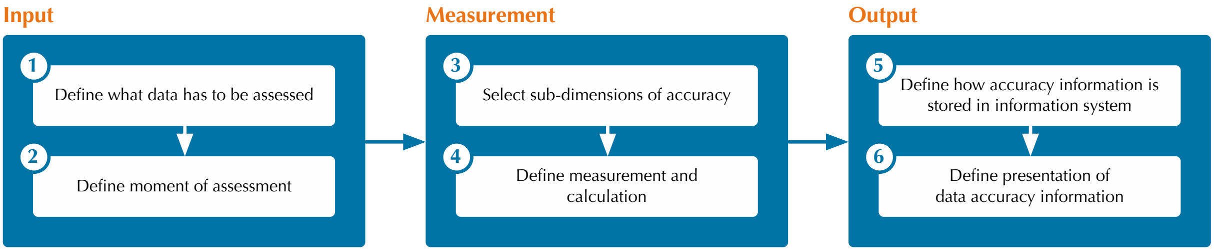


FIGURE 6.1: DATA ACCURACY ASSESSMENT GUIDE (ACTIVITIES ARE NUMBERED)

6.1.1 Input

The input actions of the assessment guide are defined following two design principles, as shown in table 6.1

TABLE 6.1: DESIGN PRINCIPLES REGARDING THE INPUT PHASE

	Principle	Based on*
2	Organisations that want to assess data accuracy should **structure their process of data collection and storage by defining moments** in their ideation phase when data has to be collected or stored to the system. This is expected to result in a more routinely assessment, leading to better estimation of accuracy to take into account in portfolio decisions.	LRQ 4, ERQ 2
9	Organisations that want to assess data accuracy should **assess the accuracy of data at the moment the data is entered into the information system.** This is expected to lead to a better estimation of accuracy, which is more valuable to take into account in portfolio decisions.	ERQ 7

*LRQ = Literature review question, ERQ = Empirical Review Question

The literature background and empirical research provided an overview of the data organisations use in portfolio decision making. Because this is the data that has to be assessed, the first action of the assessment is the inventory of what data needs to be assessed. The assessment can, however, only be performed after the data is stored to the information system. Accordingly, design principle 2 suggests that the organisation should structure the process of data collection and storage, leading to the definition of a moment when data has to be stored in the system. Next, the moment of assessment has to be defined (action 2), which is, following design principle 9, the moment the data is entered into the system.

6.1.2 Measurement

The measurement phase of the assessment guide consists of the selection of sub-dimensions of accuracy and the definition of the measurement. These actions were defined following three design principles:

TABLE 6.2: DESIGN PRINCIPLES REGARDING THE MEASUREMENT PHASE

	Principle	Based on*
4	Organisations that want to assess data accuracy should **be able to use the same assessment approach for all data because the outcome of the assessment should be comparable.** Accordingly, the outcome will be comparable regardless the type or source of data, leading to valuable estimations of accuracy to take into account in portfolio decisions.	LRQ 7, ERQ 4, ERQ 5
5	Organisations that want to assess data accuracy should **use the following sub-dimensions of accuracy: believability, coherence, complexity, consistency, objectivity, and reputation.** This is expected to lead to a better estimation of accuracy, which is more valuable to take into account in portfolio decisions.	LRQ 8, ERQ 6
8	Organisations that want to assess data accuracy should **use a subjective approach to measure data accuracy in the ideation phase.** This is expected to lead to a better estimation of accuracy, which is more valuable to take into account in portfolio decisions.	LRQ 9, ERQ 4

*LRQ = Literature review question, ERQ = Empirical Review Question

As presented by design principle 8, data accuracy assessment in the ideation phase should be performed via a subjective approach. To achieve an as reliable as possible estimation of accuracy, sub-dimensions of accuracy should be used, following design principle 5. Because a subjective approach can be used for all data, design principle 4 is also taken into account by using a subjective approach. Regarding design principle 5, the literature review led to six sub-dimensions of accuracy, listed in table 6.3.

TABLE 6.3: SUB-DIMENSIONS OF ACCURACY

	Sub-dimension	Definition
1	Believability	The extent to which data is regarded as true, correct and credible.
2	Coherence	The extent to which data is focused on one topic or real world object.
3	Consistency	The extent to which data is consistent with related other data.
4	Complexity	The extent of cognitive complexity of data relative to a particular activity.
5	Objectivity	The extent to which data is objectively collected, based on facts, and presents an impartial view.
6	Reputation	The extent to which data are trusted or highly regarded in terms of their content or source.

The first activity of the measurement phase of the assessment guide concerns the definition what sub-dimensions will be used. Organisations can decide to use the same sub-dimensions for all the data or to choose different sub-dimensions for different types of data. After appropriate sub-dimensions are chosen, the measurement and calculation have to be defined (activity 4). The sub-dimensions can be measured, for example, via a Likert scale (three or five points). Subsequently, the sub-dimensions have to be averaged (Lee et al., 2002) in order to establish an overall indicator of accuracy that will be showed to the decision makers. In case the sub-dimensions are not all considered to have the same value, the organisation can define another calculation.

6.1.3 Output

The output phase of the assessment guide consists of the definition how accuracy information is stored in the information system and how the accuracy information should be presented. These actions are defined following four design principles:

TABLE 6.4: DESIGN PRINCIPLES REGARDING THE OUTPUT PHASE

	Principle	Based on*
6	Organisations that want to use data accuracy information in portfolio decisions, should **receive a warning during the preparation of the portfolio decision in case data has a low data accuracy**. Accordingly, actions can be taken to improve the accuracy of data, leading to a better decision outcome.	ERQ 8
7	Organisations that want to use data accuracy information in portfolio decisions, should be **presented with the data accuracy information next to the evaluation criteria.** Accordingly, comparisons can be made between projects and evaluation criteria, leading to better decisions.	LRQ 6, ERQ 8

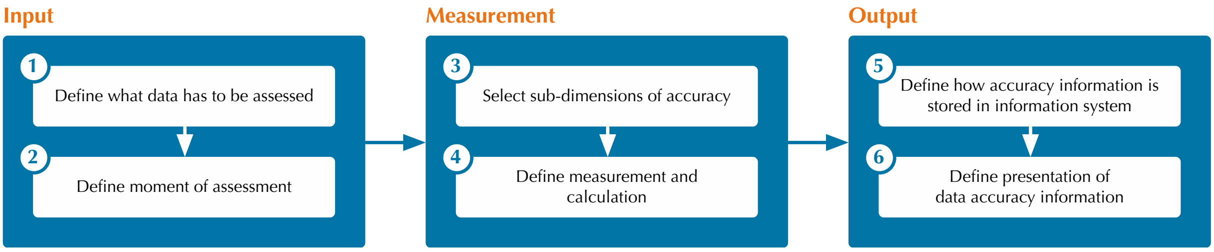
*LRQ = Literature review question, ERQ = Empirical Review Question

Regarding the storage of the level of accuracy (activity 5), it is needless to say that accuracy information should be stored in the same information system in which the data is assessed. However, following design principle 7, it is important that the outcome of the assessment should be linked both to the project and the concerning evaluation criteria. By linking the outcome of the assessment to the evaluation criteria, portfolio managers have the ability to trace back the cause of low data accuracy. Lastly, the presentation has to be defined (activity 6). This is discussed by design principle 6 and 7, which were both derived from literature and empirical research. Design principle 6 shows that during the collection of data, organisations are most interested in information concerning a low level of data accuracy, in order to take correcting actions. Design principle 7 suggests that data accuracy information should be presented next to the evaluation criteria. This gives decision makers the possibility to take the accuracy of data into account by the selection of projects, which is exactly the need described by portfolio managers during the research.

Now the translation from design principles to activities is made, the next paragraph explains the solution as a whole.

6.2 THE DATA ACCURACY ASSESSMENT GUIDE

The assessment guide designed above aims to fulfil the need of portfolio managers to have a guide that supports them in the implementation of data accuracy assessment in the ideation phase. This guide consists of six activities over three phases: input, measurement, and output.



COPY OF FIGURE 6.1: DATA ACCURACY ASSESSMENT GUIDE (ACTIVITIES ARE NUMBERED)

In input, first, an inventory has to be made of the data that needs to be assessed (activity 1). The guide is designed to assess both qualitative and quantitative, thus the inventory does not have to be limited to quantitative data. After the inventory of the data is made, the moment of assessment has to be defined (activity 2). According to the empirical research, organisations prefer to assess the data at the moment when it enters the information system. The empirical research also showed that the process of preparing the portfolio decisions (which includes data collection, storage, processing, and presentation) is performed unstructured and separated from the formalised product innovation process. As discussed in design principle 3, structuring the process that prepares portfolio decisions leads to a better accuracy assessment.

In the measurement phase of the guide, first, the sub-dimensions of accuracy have to be selected (activity 3). Organisations can make a selection of the sub-dimensions believability, coherence, complexity, consistency, objectivity, and reputation. How many sub-dimensions will be included can be chosen by the organisation, however, the empirical research showed that the sub-dimensions have to be understood by the employee that performs the assessment. After the selection of sub-dimensions, the measurement and calculation have to be defined (activity 4). The sub-dimensions can be measured by using a Likert scale, whereafter the input of the different dimensions is averaged to establish an overall level of accuracy.

In the output phase of the assessment guide, it first has to be defined how the output of the accuracy assessment will be stored to request it later (activity 5). Since the level of data accuracy is required during the portfolio decisions that are based on evaluation data, it might be most appropriate to store the output of the assessment together with the evaluation data in the information system. Here, the level of data accuracy has to be linked not only to the concerning project but also to the evaluation criterion to compare evaluation criteria with each other on data accuracy. Moreover, this gives the opportunity to trace back data with a low level of data accuracy, on which actions can be taken. Finally, the last activity of the assessment guide is the definition of how the level of data accuracy will be presented to portfolio managers and other decision makers (activity 6). The empirical research provided two recommendations for this activity: (1) in the preparation of the portfolio decision, portfolio managers want to receive a warning in case the accuracy of evaluation data is below a particular level and (2) during portfolio decisions, the level of data accuracy should be showed together with the concerning evaluation criterion.

The guide explained above should support organisations in the implementation of an accuracy assessment approach for evaluation data in the ideation phase. Because Bicore is the initiator of the current research, the guide aims to fit their portfolio management software. As discussed, this is achieved by involving Bicore in the design of the guide. However, the current research also aims to contribute to the literature and practise in general, which is achieved by the empirical research at multiple organisations. To make sure the guide can also be used at other organisations, the next paragraph validates the guide via additional interviews.

6.3 VALIDATION OF THE SOLUTION

In order to verify if the above-discussed solution solves the problem of portfolio managers and meets the design requirement, the assessment guide was verified via interviews at four organisations. In these interviews, the six activities were discussed, the list of sub-dimensions, and a possible implementation of the assessment guide. After the first two interviews, some changes were made whereafter the guide was validated again with two different portfolio managers. The next two paragraphs describe these iterations.

6.3.1 First Validation

The first validation is performed by two different clients of Bicore. These clients were earlier interviewed for the empirical research (Chapter 4) because no additional organisations were found that could be involved in the research.

Both the interviewees understood the guide and were able to explain how it could be applied to their organisation. They also mentioned their trust in a reliable estimation of data accuracy by using the sub-dimensions. Because both interviewees use the Flightmap software of Bicore, screenshots of a possible implementation in the software (Appendix E) were shown. Both the portfolio managers reacted positively on this possible implementation.

The interviewees also mentioned two possibilities for improvement. First, they argued that combining assessments of several data collectors is not taken into account in the assessment guide. This is desirable in some situations because it can happen that someone complements data that is earlier collected by someone else in the organisation. Accordingly, the accuracy assessment of the first data collector should be combined with the assessment of the second collector. This is however hard to incorporate because then the system has to track the proportion of the changes to the data and accordingly take this into account by combining the assessments. Moreover, the individual accuracy assessment is already an average of the data that entered the system. For example, by assessing the data accuracy of the market size of country A+B, it is possible that the market size of country A is believed to be accurate and the market size of other country B is believed to be inaccurate, leading to a medium level of data accuracy for country A+B. Accordingly, updating the market size of country A has a different influence on the overall data accuracy level than updating the market size of country B. As a result, more research is needed to solve this problem. However, it can be solved partially by requiring a new estimation when data is updated. This is translated to an additional recommendation for action 2 of the guide, which will be discussed in the next chapter.

The second improvement mentioned by the interviewees is that no sub-dimension takes into account that the accuracy of data can decline over time. In the empirical research, this sub-dimension was referred to as "time frame". As discussed in the empirical research, this indicator is however not appropriate to include because it seemed hard to determine how much the accuracy will decline over time. Moreover, not the accuracy of all evaluation data will decline over time. This is, however, a big opportunity for future research. An alternative solution is to update the assessment on a regular basis, for example, every year. This can be determined during the definition of the moment of assessment (action 2 in the assessment guide) and is therefore translated to an additional recommendation for action 2 of the guide.

6.3.2 Second Validation

The second validation consisted also of two interviews, resulting in a total of four organisations in which the assessment guide is validated. One of the last two organisations isn't a client of Bicore, which gave the opportunity to test the guide also in an organisation that doesn't perform portfolio management using the Flightmap software.

The portfolio managers of the second validation also understood the guide and were able to explain how it could be applied to their organisation. These portfolio managers also expressed their confidence in the subjective assessment of accuracy and reacted positively on the screenshots of a possible implementation. However, still, two points of improvement were mentioned. The first improvement mentioned is the possibility to add comments during the accuracy assessment. Via a "comment field" in the software, it should be possible to add an explanation to a particular level of data accuracy. This gives the opportunity to store for example instructions on how the level of accuracy can be improved later, leading to a better improvement. This option is included in the recommendations of the fourth action of the assessment guide.

Secondly, one of the portfolio managers asked if it was possible to store both the overall level of data accuracy in the system and the sub-dimensions of accuracy. This could possibly help the improvement of data accuracy. Accordingly, also this option is included in the recommendations to the guide, giving the organisations the possibility to incorporate it in the assessment approach.

Reflecting on the design requirements defined at the end of Chapter 5, the four interviewed portfolio managers confirmed that the developed assessment guide supports them in the implementation of an assessment approach in their own ideation phase (first design requirement). The interviewed portfolio managers understood the assessment guide and because of the subjective approach, the assessment is applicable for all types of data, both qualitative and quantitative (design requirement 2 and 3). Because it was not possible to validate the assessment guide among a large number of other decision makers, the fourth design requirement (understandability by all stakeholders) could not be validated.

6.4 CONCLUSION

This chapter described the development of the solution, based on the design principles from the literature review and empirical research. This led to the data accuracy assessment guide presented in figure 6.1. The guide consists of six activities, which support organisations in the process of implementing a data accuracy assessment in their process. Besides the six steps, paragraph 6.3 gives recommendations in how to perform the steps. An overview of the recommendations will be given in the next chapter.

The guide to implement data accuracy assessment is validated via an alpha test consisting of four interviews. The outcome of the validation was positive: portfolio managers described that the guide fulfils their need for the accuracy assessment of evaluation data. However, also four additional improvements were mentioned. These are incorporated in the recommendations to the actions of the assessment guide, which will be presented in the next chapter.

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7 Conclusion

This chapter concludes the current research by answering the research question, presenting the theoretical and practical implications, and discussing the limitations of this research as well as suggestions for future research.

7.1 ANSWER TO THE RESEARCH QUESTION

This research is initiated by Bicore to acquire knowledge in how to measure the accuracy of evaluation data in the ideation phase. This led to the following research question:

"How can organisations assess the accuracy of data in the ideation phase on which they base portfolio decisions?"

How an organisation can assess the accuracy of evaluation data in the ideation phase depends on the organisation. As a result, every organisation should develop and implement their own approach to assess data accuracy. Although these approaches will differ per organisation, four main aspects of data accuracy assessment should be the same for every organisation. These are discussed below.

First, organisations should use a subjective approach to measure evaluation data in the ideation phase. A subjective approach measures data accuracy via a survey based on sub-dimensions of accuracy. Six sub-dimensions are extracted from the literature that organisations can use: believability, coherence, consistency, complexity, objectivity, and reputation. To achieve an overall level of data accuracy, the scores on the sub-dimensions have to be averaged.

Secondly, organisations should assess the data at the moment it is saved in the information system. Empirical research showed that the process prior to this moment is unstructured, making the estimation unreliable or inefficient.

Thirdly, the level of data accuracy should be stored in the same information system as the evaluation data, making it easy to retrieve. Moreover, the level of data accuracy should not only be linked to a particular project, but also to the evaluation data itself, making it easy to trace back low levels of data accuracy.

Fourthly, the presentation of data accuracy should be focussed during the preparation of portfolio decisions on low levels of accuracy, giving portfolio managers an incentive to react on a low level of data accuracy. The empirical research showed that during portfolio decisions, decision makers want to get both informed on low and high levels of accuracy, which have to be presented next to the evaluation criteria.

To support organisations in the development and implementation of accuracy assessment in the ideation phase, a guide is developed, consisting of six actions and recommendation to these actions. The four aspects discussed above are incorporated in this guide.

7.2 DESCRIPTION OF THE FINAL SOLUTION

The solution of this project is a guide that organisations can use to implement data accuracy assessment in their ideation phase. This guide consists of six steps, as shown below.

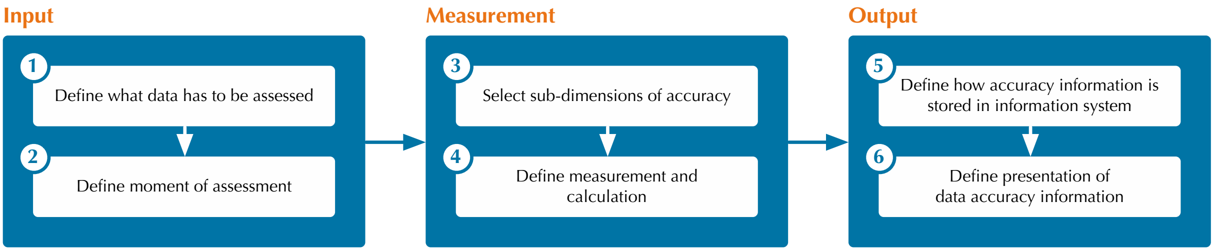

FIGURE 7.1: DATA ACCURACY ASSESSMENT GUIDE (ACTIVITIES ARE NUMBERED)

The six-step guide shows that it first has to be defined what data will be assessed (activity 1) and at what moment in the process the data will be assessed (activity 2). Next, the measurement is defined by selecting sub-dimensions of accuracy (activity 3) and determining the calculation (activity 4). Lastly, it is defined how the accuracy information is stored in the information system (activity 5) and how the information will be presented (activity 6). The literature review and empirical research resulted in recommendations for the execution of the actions, which are summarised in the table below.

TABLE 7.1: RECOMMENDATIONS ON IMPLEMENTING ACCURACY ASSESSMENT

	Action	Recommendation
1	Define what data has to be assessed	- Make an inventory of the data that has to be assessed. This can be both qualitative and quantitative data.
2	Define moment of assessment	- Structure the process of data collection and storage. - Assess the accuracy of the data at the moment it is entered into the information system. - Assess the accuracy of data when data is complemented or updated. - Assess the accuracy of data after a particular time span (e.g. one year).
3	Select sub-dimensions of accuracy	- Make a selection out of the sub-dimensions believability, coherence, consistency, objectivity, and reputation.
4	Define measurement and calculation	- Use a Likert scale (three or five points) to measure the sub-dimensions. - Average the sub-dimensions to establish an overall level of accuracy. - Give the assessor of the data the possibility to add comments to the assessment.
5	Define how accuracy information is stored in information system	- Store the accuracy information in the same information system as the evaluation data. - Store the accuracy information on the level of evaluation criteria in order to trace data with a low level of accuracy. - Store both the overall level of data accuracy in the system and the sub-dimensions of accuracy to take better correcting actions.
6	Define presentation of data accuracy information	- Present the accuracy information next to the concerning evaluation criteria. - Focus during the ideation phase on low accuracy levels to take correcting actions. - Show during the decision making both high and low levels of accuracy to compare projects with each other.

The solution is designed to fit in the existing portfolio management process (figure 7.2) which is derived from the empirical research. The assessment guide leads to the implementation of data accuracy assessment which causes two small additions to the process from data to decision, coloured orange in figure 7.2.

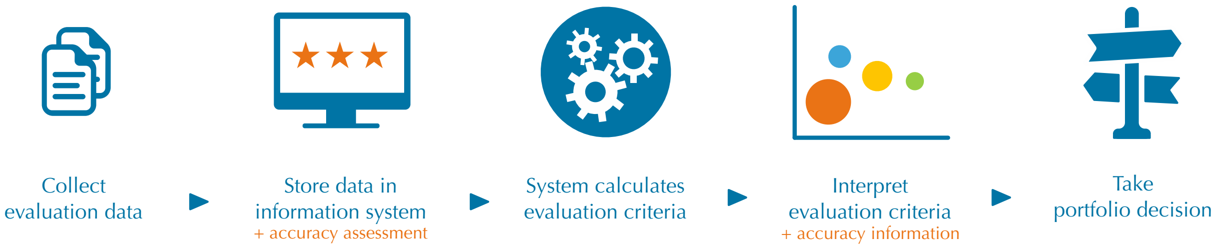

FIGURE 7.2: ACCURACY ASSESSMENT IN THE PROCESS FROM DATA TO DECISION MAKING

At the moment the portfolio manager (or data collector) stores the evaluation data in the information system, the portfolio manager should assess the evaluation data via several sub-dimensions of accuracy. The screenshots in Appendix E show how this might look in the information system after implementation. When the data is assessed, the system calculates the overall level of data accuracy. The overall level can be presented when the concerning evaluation criteria are retrieved from the system at, for example, the go-to-development gate meeting. Accordingly, the portfolio manager and other decision makers become able to take the level of accuracy into account by interpreting the evaluation criteria and taking the portfolio decision.

Reflecting on the motivation for Bicore to initiate this research, the research provides Bicore with a guide that they can use to assess the evaluation data of their clients. Moreover, since all clients use the same type of information system, the proposed subjective approach to measure data accuracy has only to be implemented once in the Flightmap software. As a result, Bicore can fulfil the need of their clients and their software has a new unique selling point.

7.3 IMPLICATIONS OF THE RESEARCH

The implications of the current research are divided into theoretical implications and practical recommendations, which will be discussed in the next two sub-paragraphs.

7.3.1 Theoretical Implications

The literature review showed several gaps in the literature regarding data use and portfolio management in the ideation phase of the product innovation process. These gaps are filled by synthesising literature knowledge from different contexts, validating these syntheses in empirical research and gathering additional knowledge via empirical research.

The current research provides five contributions to the existing literature. First, during the definition of the research, the concept of data quality is explored which led to an extensive list of data quality dimensions (Appendix D). Secondly, the focus on the dimension accuracy led to the definition of six sub-dimensions of accuracy (believability, coherence, complexity, consistency, objectivity, and reputation) which are established by consulting literature that discusses causes of low or high accuracy. Thirdly, in order to know what data is used in the ideation phase, a complete overview of relevant evaluation criteria is made by combining different sources from literature (Appendix C). This can be a contribution to the overview established by, for example, Henttonen et al. (2015). Fourthly, empirical research resulted in a characterisation how organisations in new product development deal with data and information prior to the go-to-development gate. Finally, this led to a guide that supports organisation in the development and implement of data accuracy assessment (figure 7.1). This guide can contribute to the earlier defined assessment guide by Woodall et al. (2013).

7.3.2 Practical Recommendations

Besides the theoretical implications, the current research resulted also in some practical recommendations. Portfolio managers should use the guide to define and implement data accuracy assessment in the ideation phase of their product innovation process. Different studies already proved that taking the quality of data, including accuracy, into account leads to better a decision outcome (Fischer et al., 2003; Moges et al., 2014; Shanks, 2001). The assessment guide supports organisations to put this principle into practice.

By assessing the evaluation data on accuracy, the information system provides portfolio managers with an indication of what data they can rely on and what data has a high potency to be improved. Accordingly, actions can be taken to improve the data in the information system, leading to more accurate evaluation criteria and better-supported decisions.

Lastly, Bicore can add accuracy assessment in a new version of their portfolio management software to better serve their customers and distinguish Flightmap from competitive portfolio management software that is not able to assess data accuracy.

7.3 SUGGESTIONS FOR FUTURE RESEARCH AND LIMITATIONS

During the execution of the current research, several valuable suggestions for future research came into sight. Some of them are a result of limitations of the current research, others appeared during the literature review or empirical research.

First, of all the data quality dimensions, only the accuracy dimension is taken into account which is a limitation when the overall construct of data quality needs to be measured. Although accuracy is described in the literature as an all-encompassing dimension, data might be better assessed when more data quality dimensions are taken into account. However, during the initiation of the current research, it turned out that not all data quality dimensions are appropriate to all types of data. This makes the assessment of the data more complicated since different data has to be assessed via different quality dimensions. An opportunity to solve this is via a framework that matches types of data to data quality dimensions (table 7.2). The rows of the framework distinguish between qualitative and quantitative data. The columns distinguish between information that is internally developed, internally developed and externally obtained, and externally obtained. The framework can link the evaluation data to the applicable data quality dimensions. To achieve this, empirical quantitative research is required to map the data quality dimensions in the framework. Next, the decision maker could match the concerning evaluation data to a particular cell in the framework and see what the relevant data quality dimensions are.

TABLE 7.2: FRAMEWORK TO LINK DIMENSIONS TO DATA

	Internally developed	Internally developed and externally obtained	Externally obtained
Qualitative			
Quantitative			

Secondly, another limitation of this research is the inclusion of only the first phase of the product innovation process: the ideation phase. Interviewed portfolio managers indicated that portfolio management is most important in the ideation phase, however, portfolio management is also performed in the subsequent phases of the product innovation process. As discussed in the literature review these phases differ from the ideation phase. This possibly requires another assessment approach. Moreover, the availability of more data in later phases of the innovation process creates new opportunities for the data assessment itself.

Thirdly, since including more phases of the product innovation process results in more data, this gives the opportunity to assess data accuracy via an objective approach. Moreover, assessment via an objective approach can be automated because it relies only on calculations of the data and no input of the data collector is required. This results in opportunities to assess data in more situations and on a more regular basis. However, additional research is required to determine how objective assessment can be applied in the context of new product development.

Fourthly, the next step in research regarding data accuracy in new product development might be the definition of a minimum level of accuracy a project needs to pass a gate. However, this needs thorough quantitative empirical research among organisations in new product development that have experience with data accuracy. Because these organisations are currently limited, it might be a big challenge to involve a sufficient amount of organisation in the research. However, if the outcomes of the research are significant, this has a high potential for both theory and practise.

Fifthly and final, during the validation of the guide, two opportunities for future research are discovered. One of them is how different data assessments can be merged. The other related to the time frame of accuracy: portfolio managers assumed that accuracy declines over time. It is however not clear if this applies to all data. Further research is also needed to find an approach in how to determine the degree of decline over time. If future research can achieve this together with the definition of a minimum level of accuracy, the shelf life of data can be determined which might have a big impact in both portfolio management and other research areas.

References

van Aken, J. (2004). Management research based on the paradigm of the design sciences: the quest for field–tested and grounded technological rules. Journal of management studies, 41(2), 219-246.

van Aken, J., Berends, H., & Van der Bij, H. (2012). Problem solving in organizations: A methodological handbook for business and management students. Cambridge University Press.

Ackoff, R. L. (1989). From data to wisdom. *Journal of applied systems analysis*, *16*(1), 3-9.

Baker, K. G., & Albaum, G. S. (1986). Modeling new product screening decisions. *Journal of Product Innovation Management*, *3*(1), 32-39.

Becker, B. (2006). Rethinking the Stage-Gate process—A reply to the critics. *Management Roundtable*.

Blake, R., & Mangiameli, P. (2011). The effects and interactions of data quality and problem complexity on classification. *Journal of Data and Information Quality (JDIQ)*, *2*(2), 8.

Bonner, J. M., Ruekert, R. W., & Walker, O. C. (2002). Upper management control of new product development projects and project performance. *Journal of Product Innovation Management*, *19*(3), 233-245.

Bovee M., Srivastava R. P., Mak B.R. (2001). A Conceptual Framework and Belief-Function Approach to Assessing Overall Information Quality. *Proceedings of the 6th International Conference on Information Quality.*

Brentani, U., & Reid, S. E. (2012). The fuzzy front–end of discontinuous innovation: Insights for research and management. Journal of Product Innovation Management, 29(1), 70-87.

Cabellero, I., Serrano, M., Piattini, M. (2014) A Data Quality in Use Model for Big Data. ER Workshops 2014, 65–74.

Chang, S. L., Chen, C. Y., & Wey, S. C. (2007). Conceptualizing, assessing, and managing front–end fuzziness in innovation/NPD projects. *R&D Management*, *37*(5), 469-478.

Clement, M. B. (1999). Analyst forecast accuracy: Do ability, resources, and portfolio complexity matter?. Journal of Accounting and Economics, 27(3), 285-303.

Cooper, R. G. (1999). The invisible success factors in product innovation. *Journal of product innovation management*, *16*(2), 115-133.

Cooper, R. G. (2001). Winning at New Products: Accelerating the Process from Idea to Launch, 3rd ed. *Perseus Publishing, Cambridge.*

Cooper, R. G., Edgett, S. J., & Kleinschmidt, E. J. (2000). New problems, new solutions: making portfolio management more effective. *Research-Technology Management*, *43*(2), 18-33.

Cooper, R. G. (2008). Perspective: The Stage‐Gate® idea‐to‐launch process—Update, what's new, and NexGen systems. Journal of product innovation management, 25(3), 213-232.

Cooper, R. G., & Edgett, S. J. (2012). Best practices in the idea-to-launch process and its governance. *Research-Technology Management*, *55*(2), 43-54.

Cooper, R. G. (2014). What's Next?: After Stage-Gate. *Research-Technology Management*, *57*(1), 20-31.

Crawford, C. M., & Di Benedetto, C. A. (2010). *New Products Management, 10th ed*. McGraw-Hill, New York. 19 - 22.

De Brentani, U., & Droge, C. (1988). Determinants of the new product screening decision A structural model analysis. *International Journal of Research in Marketing*, *5*(2), 91-106.

Denyer, D., Tranfield, D., & Van Aken, J. E. (2008). Developing design propositions through research synthesis. Organization studies, 29(3), 393-413.

Eisenhardt, K. M. (1989). Building theories from case study research. Academy of management review, 14(4), 532-550.

Eling, K., Langerak, F., & Griffin, A. (2013). A Stage‐Wise Approach to Exploring Performance Effects of Cycle Time Reduction. *Journal of Product Innovation Management*, *30*(4), 626-641.

Eling, K., Griffin, A., & Langerak, F. (2016). Consistency Matters in Formally Selecting Incremental and Radical New Product Ideas for Advancement. *Journal of Product Innovation Management*, *33*(S1), 20-33.

Fisher, C. W., Chengalur-Smith, I., & Ballou, D. P. (2003). The impact of experience and time on the use of data quality information in decision making. *Information Systems Research*, *14*(2), 170-188.

Gorry, G. A., & Morton, M. S. S. (1989). A framework for management information systems. *MIT Sloan Management Review*, *30*(3), 49.

Griffin, A., & Page, A. L. (1996). PDMA success measurement project: recommended measures for product development success and failure. Journal of product innovation management, 13(6), 478-496.

Hammedi, W., van Riel, A. C., & Sasovova, Z. (2011). Antecedents and consequences of reflexivity in new product idea screening. *Journal of Product Innovation Management*, *28*(5), 662-679.

Hauser, J., Tellis, G. J., & Griffin, A. (2006). Research on innovation: A review and agenda for marketing science. *Marketing science*, *25*(6), 687-717.

Hart, S., Hultink, E., Tzokas, N., & Commandeur, H. R. (2003). Industrial companies' evaluation criteria in new product development gates. Journal of Product Innovation Management, 20(1), 22-36.

Heising, W. (2012). The integration of ideation and project portfolio management—A key factor for sustainable success. *International Journal of Project Management*, *30*(5), 582-595.

Henttonen, K., Ojanen, V., & Puumalainen, K. (2015). Searching for appropriate performance measures for innovation and development projects. R&D Management, 46(5), 914-927.

Holahan, P. J., Sullivan, Z. Z., & Markham, S. K. (2014). Product development as core competence: How formal product development practices differ for radical, more innovative, and incremental product innovations. *Journal of Product Innovation Management*, *31*(2), 329-345.

Huang, H., Stvilia, B., Jörgensen, C., & Bass, H. W. (2012). Prioritization of data quality dimensions and skills requirements in genome annotation work. Journal of the Association for Information Science and Technology, 63(1), 195-207.

IBM. (2016) The Four V's of Big Data. Retrieved March 01, 2017, from http://www.ibmbigdatahub.com/infographic/four-vs-big-data

Jonas, D., Kock, A., & Gemünden, H. G. (2013). Predicting project portfolio success by measuring management quality—a longitudinal study. *IEEE Transactions on Engineering Management*, *60*(2), 215-226.

Kahn, K. B. (2002). An exploratory investigation of new product forecasting practices. *Journal of Product Innovation Management*, *19*(2), 133-143.

Kelly, D., & Storey, C. (2000). New service development: initiation strategies. *International Journal of Service Industry Management*, *11*(1), 45-63.

Khurana, A., & Rosenthal, S. R. (1998). Towards holistic “front ends” in new product development. Journal of product innovation management, 15(1), 57-74.

Kihlander, I., & Ritzén, S. (2012). Compatibility before completeness—Identifying intrinsic conflicts in concept decision making for technical systems. *Technovation*, *32*(2), 79-89.

Kim, J., & Wilemon, D. (2010). Accelerating the fuzzy front-end of NPD projects: methods and management. *International Journal of Engineering Management and Economics*, *1*(1), 80-101.

Kock, A., Heising, W., & Gemünden, H. G. (2015). How Ideation Portfolio Management Influences Front‐End Success. *Journal of Product Innovation Management*, *32*(4), 539-555.

Koen, P., Ajamian, G., Burkart, R., Clamen, A., Davidson, J., D'Amore, R., and Karol, R. (2001). Providing clarity and a common language to the “fuzzy front end”. *Research-Technology Management*, *44*(2), 46-55.

Koen, P. A., Ajamian, G. M., Boyce, S., Clamen, A., Fisher, E., Fountoulakis, S., ... & Seibert, R. (2002). *Fuzzy front end: effective methods, tools, and techniques*. Wiley, New York, NY.

Kornish, L. J., and Ulrich, K. T. (2014). The importance of the raw idea in innovation: Testing the sow's ear hypothesis. *Journal of Marketing Research*, *51*(1), 14-26.

Laranjeiro, N., Soydemir, S. N., & Bernardino, J. (2015, November). A survey on data quality: classifying poor data. In Dependable Computing (PRDC), 2015 IEEE 21st Pacific Rim International Symposium on (pp. 179-188). IEEE.

Lee, Y. W., Pipino, L. L., Funk, J. D., & Wang, R. Y. (2006). Journey to data quality. The MIT Press.

Lenfle, S., & Loch, C. (2010). Lost roots: how project management came to emphasize control over flexibility and novelty. *California Management Review*, *53*(1), 32-55.

Martinsuo, M., & Poskela, J. (2011). Use of evaluation criteria and innovation performance in the front end of innovation. *Journal of Product Innovation Management*, *28*(6), 896-914.

Moges, H. T., Van Vlasselaer, V., Lemahieu, W., & Baesens, B. (2016). Determining the use of data quality metadata (DQM) for decision making purposes and its impact on decision outcomes—An exploratory study. *Decision Support Systems*, *83*, 32-46.

Morse, J. M. (1995). The significance of saturation.

Naumann, F., & Rolker, C. (2005). Assessment methods for information quality criteria. Humboldt-Universität zu Berlin, Mathematisch-Naturwissenschaftliche Fakultät II, Institut für Informatik.

Pipino, L. L., Lee, Y. W., & Wang, R. Y. (2002). Data quality assessment. *Communications of the ACM*, *45*(4), 211-218.

Prat, N., & Madnick, S. (2008, January). Measuring data believability: A provenance approach. In Hawaii International Conference on System Sciences, Proceedings of the 41st Annual (pp. 393-393). IEEE.

Reinertsen, D. (1994). Streamlining the fuzzy front-end. *World Class Design to Manufacture*, *1*(5), 4-8.

van Riel, A. C., Semeijn, J., Hammedi, W., & Henseler, J. (2011). Technology-based service proposal screening and decision-making effectiveness. *Management Decision*, *49*(5), 762-783.

Romme, A. G. L. (2003). Making a difference: Organization as design. Organization science, 14(5), 558-573.

Romme, A. G. L., & Endenburg, G. (2006). Construction principles and design rules in the case of circular design. Organization science, 17(2), 287-297.

Schaal, M., Smyth, B., Mueller, R. M., & MacLean, R. (2012). Information quality dimensions for the social web. In Proceedings of the International Conference on Management of Emergent Digital EcoSystems (pp. 53-58). ACM.

Schmidt, J. B., Sarangee, K. R., & Montoya, M. M. (2009). Exploring new product development project review practices. Journal of Product Innovation Management, 26(5), 520-535.

Sethi, R., & Iqbal, Z. (2008). Stage-gate controls, learning failure, and adverse effect on novel new products. *Journal of Marketing*, *72*(1), 118-134.

Shankaranarayanan, G., Zhu, B., & Cai, Y. (2008). Decision Support with Data Quality Metadata. In *ICIQ* (pp. 281-295).

Simon, H. A. (1960). The new science of management decision.

Simon, H. A. (1988). Creativity and motivation: A response to Csikszentmihalyi. New Ideas in Psychology, 6(2), 177-181.

Strong, D. M., Lee, Y. W., & Wang, R. Y. (1997). Data quality in context. *Communications of the ACM*, *40*(5), 103-110.

Stvilia, B., Gasser, L., Twidale, M. B., & Smith, L. C. (2007). A framework for information quality assessment. Journal of the Association for Information Science and Technology, 58(12), 1720-1733.

Terwiesch, C., & Ulrich, K. T. (2009). Innovation tournaments: Creating and selecting exceptional opportunities. Harvard Business Press.

Thomke, S., & Fujimoto, T. (2000). The Effect of "Front–Loading" Problem–Solving on Product Development Performance. *Journal of product innovation management*, *17*(2), 128-142.

Tzokas, N., Hultink, E. J., & Hart, S. (2004). Navigating the new product development process. *Industrial Marketing Management*, *33*(7), 619-626.

UNECE/HLG. (2014). A Suggested Framework for the Quality of Big Data

Van Burg, E., Romme, A. G. L., Gilsing, V. A., & Reymen, I. M. (2008). Creating University Spin–Offs: A Science–Based Design Perspective. Journal of Product Innovation Management, 25(2), 114-128.

Veldhuizen, E., Hultink, E. J., & Griffin, A. (2006). Modeling market information processing in new product development: An empirical analysis. Journal of Engineering and Technology Management, 23(4), 353-373.

Wang, R. Y., & Strong, D. M. (1996). Beyond accuracy: What data quality means to data consumers. *Journal of management information systems*, *12*(4), 5-33.

Woodall, P., Borek, A., & Parlikad, A. K. (2013). Data quality assessment: the hybrid approach. Information & management, 50(7), 369-382.

Yin, R. (2003). Case study research: Design and methods (Vol. 3). California: Sage Publications.

Zahay, D., Griffin, A., & Fredericks, E. (2004). Sources, uses, and forms of data in the new product development process. *Industrial Marketing Management*, *33*(7), 657-666.

Zahay, D., Griffin, A., & Fredericks, E. (2011). Information use in new product development: an initial exploratory empirical investigation in the chemical industry. *Journal of Product Innovation Management*, *28*(4), 485-502.

Zhang, Q., & Doll, W. J. (2001). The fuzzy front end and success of new product development: a causal model. European Journal of Innovation Management, 4(2), 95-112.

Appendix A: Interview Guide

Part 1: Portfolio Decisions

Q1: Can you tell me something about how you take **portfolio decisions**? Who does them take, when and how?

Consider the product innovation process in the appendix.

Q2: Does the innovation process your R&D department follows also have a **go-to-development gate?**

Q3: What **evaluation criteria** (or information) do you use in the go-to-development gate?

Q4: Do the evaluation criteria **vary among projects?** If yes, do you have an explanation for this?

Part 2: Data use in portfolio decisions

For this interview, we consider data and information to be the same.

Q5: Taking the earlier discussed evaluation criteria into account, can you distinguish **categories of data** you need for making portfolio decisions?

Q6: What are the **sources** of this data?

Q7: **How** is this data currently **collected?**

Q8: **Where** is this data **stored?**

Q9: What **category** of data do you consider as **most important?**

Part 3: Accuracy of Data Used in Portfolio Decisions

Q10: Do you currently **take the accuracy** of this data **into account?** If yes, how?

Q11: If you take the accuracy into account, do you use different **dimensions of data accuracy?**

Q12: Do you **consider** taking this accuracy into account **as important?**

Q13: How would you **describe low data accuracy?**

Q14: In case you doubt about the data accuracy, what **questions** do you ask to **validate the data accuracy?**

Q14: How can the **data provider give you confidence** about the accuracy of the data?

The appendix shows seven data quality dimensions.

Q15: Can you **rank the dimensions** from very important to not important?

Q16: What dimensions are **most critical/important** to your opinion?

The next questions focus on the accuracy dimension.

Q17: What could be **causes of low accuracy?**

Q18: What could be **indicators of low accuracy?** (How do you **recognise a low accuracy?**)

Part 4: Data Accuracy Assessment Guide

Assume that there is a guide to measure the accuracy of data that is used in portfolio decisions.

Q19: At **what moment** in the innovation process is this information regarding the **accuracy** of used data **most important?**

Q20: In case **additional information is needed** to measure the accuracy of the data, do you prefer to give this information by entering the information or by requesting the accuracy of the data?

Q21: Is information about **high and low accuracy** of the same value?

Appendix B: Coding Template

Coding category	Specific category	Keywords
Context	Organisation strategy Responsibilities	Business unit, roadmap, strategy, strategic planning, incremental radical, product line, resource allocation
Ideation phase	Innovation process Existence of go-to-development gate	Go-to-development gate, gate meeting, milestone, project approach, product definition, business case, value proposition
Portfolio management	Decision makers Evaluation criteria Categories of data Collection of data	Portfolio decision, project criteria, data type, data category, market criteria, strategic criteria, technical criteria, financial criteria, product data, evaluation data, market research, feasibility research, information system, data storage, Excel
Data accuracy	Current approach Dimensions of accuracy Presentation of data accuracy	Compare data, discuss data, accuracy, believability, coherence, complexity, consistency, objectivity, reputation, level of accuracy, presentation

Appendix C: Commonly Used Evaluation Criteria

Market-based criteria	**Description**
Customer acceptance [1, 2, 3, 4]	Proportion of customers that is willing to use the product
Customer satisfaction [1, 2, 3, 4]	Rating of how satisfied customers are
Sales in units [1, 2, 3]	Number of products sold
Market share [1, 2, 4]	Proportion of market that is captured by the firm
Revenue [1, 2, 4]	Amount of revenue the product generates
Sales growth [2, 3]	Growth of revenue the product generates
Market potential [2, 3]	Estimated maximum total revenue the product can generate
Portfolio fit [3]	Rating of how well the product fits into the existing portfolio
Chance to be first to market [3]	Likelihood to be the first firm that launches the type of product
Market growth [3]	Growth of the market to which the product belongs
Financial-based criteria	**Description**
Break-Even time [1, 2, 3, 4]	Time it takes to earn back the development costs
Profit [1, 2, 3, 4]	Profit that the product will generate
IRR [1, 2, 3, 4]	Internal rate of return, measuring the profitability of potential investment
ROI [1, 2, 3, 4]	Return on investment; (gain of investment — costs) ÷ costs
Margin [1, 2, 4]	Measurement of profitability; profit ÷ revenue
Stay within budget [2, 3]	Scoring whether the project is developed within its development budget
NPV [3]	Net present value; cash flow ÷ $(1 + \text{discount rate})^{\text{time of cash flow}}$
Risk taking [4]	Rating of amount of risk involved
Product-based criteria	**Description**
Product performance [1, 2, 3]	Scoring of how well the functional requirements are met
Product quality [1, 2, 3]	Scoring of how well the non-functional requirements are met
Time-to-market [1, 2, 4]	Time it takes to launch the product
Introduced in time [1, 2]	Evaluation whether the product is launched on time
Development costs [1, 4]	Total development costs of the product
Level of innovativeness [1, 4]	Scoring of how innovative the product is
Technical feasibility [2, 3]	Scoring of how feasible the development of the product is
Competitive advantage [1]	Advantage that the firm has over its competitors
Product uniqueness [2]	Scoring of product uniqueness
Potential for patents [3]	Estimation if the product can be protected via patents
Technical synergy [3]	Scoring of how well projects complement each other

[1] Mentioned by Griffin and Page (1996)
[2] Mentioned by Hart, et al. (2003)
[3] Mentioned by Schmidt et al. (2009)
[4] Mentioned by Henttonen et al. (2015)

Appendix D: Overview Data Quality Dimensions

Dimension	Article number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	in % of articles used
Timeliness	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	100%
Completeness	■	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■	■		■	■	■	91%
Accuracy	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	91%
Consistency		■	■	■	■			■	■				■	■	■	■	■	■	■	■	■	■	73%
Accessibility	■			■		■		■	■	■		■	■	■	■	■		■	■		■	■	68%
Relevancy	■	■					■	■	■	■	■	■	■	■		■		■	■				59%
Interpretability	■	■			■		■			■		■	■			■		■	■				45%
Security	■						■	■	■	■		■		■				■	■		■		45%
Understandability		■					■			■		■			■	■		■	■			■	41%
Concise representation	■	■					■			■		■				■		■	■				36%
Reputation	■						■			■		■		■				■	■				32%
Appropriate amount of data	■						■			■		■				■			■				27%
Availability							■	■							■	■		■				■	27%
Believability	■						■			■		■						■	■				27%
Precision		■				■								■	■	■						■	27%
Usability		■				■					■					■		■			■		27%
Value-added	■						■			■						■		■	■				27%
Contextual	■													■		■	■					■	23%
Efficiency		■													■	■		■				■	23%
Flexibility		■						■	■							■		■					23%
Objectivity	■						■			■		■						■					23%
Portability					■			■	■						■	■							23%
Validity			■			■								■		■					■		23%
Credibility													■		■	■						■	18%
Intrinsic	■													■		■	■						18%
Naturalness								■	■					■				■					18%
Reliability		■					■									■		■					18%
Representational	■				■				■							■							18%
Representational consistency	■				■			■	■														18%
Traceability															■	■			■			■	18%
Verifiability							■							■		■		■					18%
Ability to present null values					■			■	■														14%
Appropriateness					■			■	■														14%
Clarity		■				■			■														14%
Coherence														■				■			■		14%
Complexity														■				■			■		14%
Compliance															■	■						■	14%
Confidentilliaty															■	■						■	14%
Correctness				■					■											■			14%
Cost							■	■	■														14%
Documentation							■	■								■							14%
Format		■			■			■															14%
Format precision					■			■	■														14%

Where: ■ dimension is used in corresponding article.

Dimension	Article number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	in % of articles used
Identifiability								■	■								■						14%
Informativeness		■												■				■					14%
Inherent						■									■	■							14%
Privacy of users								■	■												■		14%
Recoverability															■	■						■	14%
Redundancy								■	■					■									14%
Scope		■			■											■							14%
System-related		■													■	■							14%
Attribute granularity								■	■														9%
Comprehensiveness								■	■														9%
Content		■			■																		9%
Data model					■				■														9%
Data values					■				■														9%
Ease of manipulation										■									■				9%
Ease of operation												■						■					9%
Ease of understanding	■							■															9%
Homogeneity								■	■														9%
Latency							■											■					9%
Level of detail		■			■																		9%
Metadata									■												■		9%
Obtainability								■	■														9%
Operational																■						■	9%
Precision of domains								■	■														9%
Relevance													■						■				9%
Response time							■											■					9%
Robustness								■	■														9%
Semantic																	■	■					9%
Simplicity								■	■														9%
Source								■													■		9%
Structure								■									■						9%
Use of storage								■	■														9%
Volatility														■				■					9%

Where: ■ dimension is used in corresponding article.

References to articles:

1 Wang, R. Y., & Strong, D. M. (1996). Beyond accuracy: What data quality means to data consumers. *Journal of management information systems*, *12*(4), 5-33.

2 Wand, Y., & Wang, R. Y. (1996). Anchoring data quality dimensions in ontological foundations. *Communications of the ACM*, *39*(11), 86-95.

3 Cykana, P., Paul, A., & Stern, M. (1996). DoD Guidelines on Data Quality Management. In *IQ* (pp. 154-171).

4 Gardyn, E. (1997, October). A Data Quality Handbook for a Data Warehouse. In *IQ* (pp. 267-290).

5 Redman, T. C., & Blanton, A. (1997). *Data quality for the information age*. Artech House, Inc..

6 Allen, I. E. (2000). Improving Data Warehouse and Business Information Quality: Methods for Reducing Costs and Increasing Profits. *Quality Progress*, *33*(5), 125.

7 Naumann, F., & Rolker, C. (2000). Assessment methods for information quality criteria.

8 Redman, T. C. (2001). Data quality: the field guide. Digital press.

9 Loshin, D. (2001). Enterprise knowledge management: The data quality approach. Morgan Kaufmann.

10 Pipino, L. L., Lee, Y. W., & Wang, R. Y. (2002). Data quality assessment. *Communications of the ACM*, *45*(4), 211-218.

11 Long, J., & Seko, C. (2002). A New Method for Database Data Quality Evaluation at the Canadian Institute for Health Information (CIHI). In *IQ* (pp. 238-250).

12 Lee, Y. W., Strong, D. M., Kahn, B. K., & Wang, R. Y. (2002). AIMQ: a methodology for information quality assessment. *Information & management*, *40*(2), 133-146.

13 Bovee, M., Srivastava, R. P., & Mak, B. (2003). A conceptual framework and belief–function approach to assessing overall information quality. *International journal of intelligent systems*, *18*(1), 51-74.

14 Stvilia, B., Gasser, L., Twidale, M. B., & Smith, L. C. (2007). A framework for information quality assessment. *Journal of the Association for Information Science and Technology*, *58*(12), 1720-1733.

15 International Organization for Standardization/International Electrotechnical Commission. (2008). Software engineering-Software product Quality Requirements and Evaluation (SQuaRe) Data quality model. *ISO/IEC*, *25012*.

16 Moraga, C., Moraga, M. Á., Caro, A., & Calero, C. (2009). SPDQM: SQuaRE-aligned portal data quality model. In *Ninth International Conference on Quality Software, QSIC* (pp. 24-25).

17 Loshin, D. (2010). The practitioner's guide to data quality improvement. Elsevier.

18 Schaal, M., Smyth, B., Mueller, R. M., & MacLean, R. (2012, October). Information quality dimensions for the social web. In *Proceedings of the International Conference on Management of Emergent Digital EcoSystems* (pp. 53-58). ACM.

19 Huang, H., Stvilia, B., Jörgensen, C., & Bass, H. W. (2012). Prioritization of data quality dimensions and skills requirements in genome annotation work. *Journal of the American Society for Information Science and Technology*, *63*(1), 195-207.

20 Liaw, S. T., Rahimi, A., Ray, P., Taggart, J., Dennis, S., de Lusignan, S., ... & Talaei-Khoei, A. (2013). Towards an ontology for data quality in integrated chronic disease management: a realist review of the literature. *International journal of medical informatics*, *82*(1), 10-24.

21 UNECE/HLG. (2014). A suggested Framework for the Quality of Big Data: Deliverables of the UNECE Big Data Quality Task Team. *Project Deliverable Big Data Quality Framework*.

22 Caballero, I., Serrano, M., & Piattini, M. (2014, October). A data quality in Use model for Big Data. In *International Conference on Conceptual Modeling* (pp. 65-74). Springer International Publishing.

Appendix E: Screenshots Potential Implementation