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Entwicklung einer Methodik zur Unterstützung der Entscheidungsfindung auf der Grundlage heuristischer Entscheidungen in der Produktentwicklung und im Innovationsmanagement

Developing a method to support decision making based on heuristic decisions in product development and innovation management

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Entwicklung einer Methodik zur Unterstützung der Entscheidungsfindung auf der Grundlage heuristischer Entscheidungen in der Produktentwicklung und im Innovationsmanagement

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Wissen ist einer der entscheidenden Faktoren in den Volkswirtschaften unserer Zeit. Der Unternehmenserfolg wird mehr denn je davon abhängen, wie schnell ein Unternehmen neues Wissen aufnehmen, zugänglich machen und verwerten kann. Die Aufgabe eines Universitätsinstitutes ist es, hier einen wesentlichen Beitrag zu leisten. In den Forschungsarbeiten wird ständig Wissen generiert. Dieses kann aber nur wirksam und für die Gemeinschaft nutzbar werden, wenn es in geeigneter Form kommuniziert wird. Diese Schriftenreihe dient seit mehr als 20 Jahren als eine Plattform zum Transfer und macht damit das Wissenspotenzial aus aktuellen Forschungsarbeiten am IPEK - Institut für Produktentwicklung Karlsruhe* am Karlsruher Institut für Technologie (KIT) verfügbar. Die Forschung des IPEK ist dabei strukturiert in die Kategorien Systeme, Methoden und Prozesse, um so der Komplexität heutiger Produktentwicklung ganzheitlich gerecht zu werden. Erst die Verknüpfung dieser drei Kategorien ermöglicht die Synthese innovativer Systeme durch Nutzung neuester Methoden und Prozesse. Gleichzeitig werden durch die Systemsynthese die erforschten neuen Methoden und Prozesse validiert und deren Mehrwert für die Praxis abgesichert. Dieses Forschungskonzept prägt nicht nur das IPEK-Leitbild, sondern auch den Charakter dieser Schriftenreihe, da immer alle drei Kategorien und deren Wechselwirkungen berücksichtigt werden. Jeder Band setzt hier individuelle Schwerpunkte und adressiert dabei folgende Forschungsgebiete des IPEK:

- das Entwicklungs- und Innovationsmanagement,
- die Entwicklungs- und Konstruktionsmethodik,
- der Leichtbau von der Ebene des ganzen Systems bis hinunter zur Optimierung des Bauteils,
- die Validierung technischer Systeme auch unter Berücksichtigung der NVH Aspekte (Noise, Vibration, Harshness) mit dem Fokus auf Schwingungen und Akustik an Komponenten und in den Gesamtsystemen sowie deren subjektiver Beurteilung durch den Menschen,
- die Antriebssystemtechnik mit den Schwerpunkten komplette Antriebslösungen für Fahrzeuge und Maschinen,
- das Design, die Tribologie und Erprobung von Kupplungen und Bremsen sowie
- die Gerätetechnik mit dem Schwerpunkt auf Power-Tools.

Die Forschungsberichte stellen Ergebnisse unserer Forschung sowohl anderen Wissenschaftlern als auch den Unternehmen zu Verfügung um damit die Produktentwicklung in allen ihren Facetten mit innovativen Impulsen zu optimieren

Albert Albers und Sven Matthiesen

Vorwort zu Band 132

Die moderne Produktentwicklung hat zum Ziel, marktgerechte Produkte und technische Systeme zu erzeugen, die den auf den Märkten geforderten Kunden- und Anwendernutzen befriedigen und dabei gleichzeitig den Anbieternutzen im Sinne einer entsprechenden Renditebildung im Unternehmen sicherstellen. Dabei ist zu berücksichtigen, dass in den heutigen globalen Käufermärkten ein extremer Wettbewerb herrscht und gleichzeitig die Produktlösungen, insbesondere durch die Kombination von Mechanik, Elektrik und Software zu mechatronischen Gesamtlösungen, zunehmend komplexer geworden sind. Grundsätzlich kann die Produktentwicklung als ein kontinuierlicher Prozess aus dem Wechsel zwischen Synthese- und Analyseaktivitäten beschrieben werden. Hier hat die Gruppe um ALBERS in den letzten Jahren umfangreiche methodische und prozessorientierte Lösungen dargestellt. Eine Kernhypothese ist dabei das Zurückführen von Produktentwicklungsaufgaben auf Problemlösungsprozesse. Diese Problemlösungsprozesse haben zum Ziel, einen vorliegenden Istzustand, zum Beispiel die aktuellen technischen Lösungen für eine Aufgabenstellung am Markt, hin zu einem neuen Sollzustand, also neue technische Lösungen für diese Aufgabenstellung mit einem höheren Potenzial zu beschreiben. Grundsätzlich bedeutet Problemlösung dabei unter anderem eine permanente Entscheidung zwischen Alternativen. Dieses Entscheiden im Produktentstehungsprozess geschieht nur in sehr wenigen Fällen ausführlich methodisch strukturiert und mit einer harten dedizierten Vorgehensweise. Viel öfter ist der Typus der heuristischen Entscheidung im Produktentwicklungsprozess, wo Menschen aufgrund ihrer Erfahrung, ihres Hintergrunds und auch der aktuellen Situation alleine oder in Gruppen viele Entscheidungen spontan treffen, die dann den Fortgang des Produktentstehungsprozesses aber oft sehr stark beeinflussen. Dieser Prozess der sogenannten heuristischen Entscheidungsfindung ist also im Alltag der Produktentwicklung von großer Bedeutung. Ihn besser zu verstehen und methodisch zu unterstützen ist eine Aufgabe, der sich Frau Narucha Tanaiutchawoot in ihrer wissenschaftlichen Arbeit gestellt hat. Sie möchte dabei als Teil der *KaSPro – Karlsruher Schule für Produktentwicklung* eine Methoden zur Unterstützung der Entscheidungsfindung erarbeiten, die vor allem dafür sorgen, dass der sogenannte kognitive Bias reduziert wird. Der kognitive Bias beschreibt die individuelle Beeinfussung von Menschen bei heuristischen Entscheidungen durch die Randbedingungen. Diesen Effekt zu untersuchen und Methoden zur Vermeidung vorzuschlagen ist Kern der Arbeit. Sie leistet damit einen Beitrag zum besseren Verständnis der Entscheidungsfindung in der Praxis und schlägt unterstützende Methoden vor.

Dezember, 2020 Albert Albers

Kurzfassung

Die Entscheidungsfindung ist ein wichtiger Faktor, der die Produktentwicklung so steuert, dass sie auf dem Markt erfolgreich ist oder scheitert. Die meisten Entscheidungen beruhen auf den verfügbaren Informationen, Berechnungen und Analysen verschiedener systematischer Methoden. Diese Methoden können jedoch keine definitiv richtige und gute Entscheidung liefern, insbesondere unter Unsicherheit und begrenzten Informationen. Die Entscheidungsfindung mit einfachen Strategien und mentalen Prozessen, die heuristische Entscheidungen genannt werden, wird dann automatisch angewendet, um eine Lösung zu finden. Obwohl Heuristiken in vielen Situationen hilfreich sind, können sie zu Entscheidungsverzerrungen führen.

Diese Forschung zielt darauf ab, das Auftreten Entscheidungsverzerrungen bei der Verwendung von Heuristiken zur Entscheidungsfindung zu untersuchen. Dies zu verstehen und sich dessen bewusst zu sein, ist wichtig für die Verbesserung der Entscheidungseffizienz. Darüber hinaus wurden die De-Biasing Techniken entwickelt, um kognitive Probleme zu lösen und Entscheidungsfehler zu reduzieren, die durch Entscheidungsverzerrungen verursacht werden.

Informationen aus der Literatur und empirischen Studien zeigen viele Erscheinungen von heuristischen Entscheidungen und Verzerrungen während der Entscheidungsfindung in verschiedenen Aktivitäten der Produktentwicklung - insbesondere bei der Priorisierung von Alternativen und der Auswahl der Lösung. Methoden zum Umgang mit den Entscheidungsverzerrungen bei der Entscheidungsfindung in der Produktentwicklung wurden dann durch die Modifizierung verfügbarer Techniken aus anderen Bereichen entwickelt und zur Behandlung der kognitiven Vorurteile bei der Entscheidungsfindung in der Produktentwicklung angewandt. Es wurden vier Arten von De-Biasing Techniken entwickelt und in einem Rahmenwerk vorgeschlagen, die in Experimenten unter simulierten und realen Situationen angewandt und ausgewertet wurden.

Die Ergebnisse zeigen, dass Entscheidungsverzerrungen mit verschiedenen Entzerrungstechniken auf der Grundlage der Ziele und Ableitung von Vorurteilen behandelt werden kann. Diese Techniken können mit einer Art von Verzerrung umgehen, aber auch zu einer anderen Art von Verzerrung führen. Darüber hinaus gibt es keine Antwort darauf, dass Entscheidungen mit oder ohne Verzerrungen eine korrekte Lösung bieten können. Daher ist die geeignetste Methode zur Behandlung von Entscheidungsverzerrungen in der Produktentwicklung, das Bewusstsein der Entscheidungsträger für heuristische Entscheidungen und Verzerrungen zu schärfen. Somit kann der Entscheidungsträger entscheiden, die Entscheidungen und Lösungen zu akzeptieren oder abzulehnen.

Abstract

Decision making is an important factor that controls product development to be success or fail in the market. Most decisions rely on the available information, calculation, and analysis of different systematic methods. However, these methods cannot definitely provide a correct and good decision, especially under uncertainty and limited information. Making a decision using simple strategies and mental processes called heuristic decision is then automatically applied to find a solution. Even if heuristics are helpful in many situations, they can lead to decision biases.

This research aims to investigate the appearance of decision biases when using heuristics to make a decision in product development. Understanding and being aware of this is important in improving decision efficiency and ability. Moreover, the de-biasing techniques are developed to deal with cognitive biases. These techniques are used to reduce decision errors caused by decision biases in heuristic decisions.

Information from the literature and empirical studies show many appearances of heuristic decisions and biases during decision making in different activities of product development- especially when prioritizing alternatives and selecting the solution. Methods or tools to handle the decision biases while making the decision in product development were then developed by modifying available techniques from other fields. Four types of de-biasing techniques were developed and proposed in a framework, which were applied and evaluated in experiments under simulated and real situations.

The results showed that decision biases can be handled using different de-biasing techniques based on the objectives and resources of biases. These techniques can handle one bias, but can also lead to another type of bias. Moreover, there is no answer that decisions with or without biases can provide a correct solution. Therefore, the most suitable method to deal with cognitive biases in product development is to raise the decision makers' awareness of heuristic decisions and biases. Then the decision maker can decide to accept or reject the decisions and solutions.

Preface

This research has been done during my study at the IPEK-Institute for Product Development in the EMM-Design Method and Design Management. The first person I would like to say thank you to is Dr.Ing. Nikola Bursac. He is the first person I met and introduced this research topic to me. He motivated and showed me how the heuristic decisions and cognitive biases are interesting in the product development process.

Then I would like to say thank you to Pro. Dr. Ing. Dr. h. c. Albert Albers, who is the head of this institute and gave me a chance to work here with a warm welcome.

During my working time, I had many opportunities to work with different people in the institute including the administrative team, IT team, and other research groups.

I also have participated in many activities such as the IP project, PROVIL project, and AIL project, which helped me get more experience in developing products with different company partners under a simulated situation. Everyone was very kind to me and always supported me when I had questions and problems.

One of the most important people who made much effort to support me is M.Sc. Simon Rapp. We had a weekly meeting where I could discuss many topics with him, such as design experiments, results, procedures for the research and general problems. He is the person who always pushed me in a good direction and gave me inspiration when I was depressed. I would say that I could not finish this research without him.

The last group in the institute that I would like to say thank you is my group leader, M.Sc. Florian Marthalar and chief engineer, Dipl. Ing. Markus Spadinger. They reviewed and revised all of my work such as research proposal, thesis, and all presentation and discussion with Pro. Albers. They encouraged me and provided excellent suggestions, helping me to improve myself and grow.

At the end of this part, I would like to give many thanks to my family and lovely family in Germany who always understand me and support me in every situation. I cannot stay abroad without their support. I would say that success in the research does not come from only one person or from one group, but comes from many directions and persons who are involved in our life. Achieving the final destination is not important when comparing to what we can get and learn during the way before reaching the final goal.

Karlsruhe, 26. June 2020

Narucha Tanaiutchawoot

“The decisions you make today will not just affect your tomorrow but will determine your future“

Keith Craft

Outline

Figure

Table

1 Introduction

New technologies and innovative products have been introduced and launched in the global market. Some products are successful in the market, which are innovations. However, some products are losing in the market. The level of achievement of the product in the market depends on the efficiency of the product development process that can be described by the model of PGE - Product Generation Engineering from Albers (Albers, A., Bursac, N., & Rapp, S, 2016). The procedures in this process vary and rely on strategies, methods, and policy in each company. Higher efficiency in product development processes such as low time, effort, and budget of production can lead the product to have a high chance of success in the market.

The product development processes consist of many activities including product engineering activities such as production and basic activities to support, improve and secure the product development process such as management and validation. These processes require cooperation from different departments to foster a holistic assessment of the new product development project over the entire process. Management is urged to assess the market, financial, and legal aspects of the projects to define deliverables and clear go/no-go decision criteria at each stage, which encourages task completion and decision making (Griffin & Hauser, 1996; Lint & Pennings, 2001). Joakim (Joakim, Björn & Sofi, 2007) identified the decision-making process to be one factor that influences the outcome of collaborative product development projects. Decision makers, decision levels, and decision rules affect the decision process to produce innovative products (McCarthy, Tsinopoulos, Allen & Rose-Anderssen, 2006a).

Decision making in product development can be categorized into three levels (McCarthy, Tsinopoulos, Allen & Rose-Anderssen, 2006b). The decision at the highest level related to the market and product strategy, and the fund management of project portfolios, which are called strategic decisions. These decisions set the initial aims and objectives of the project and oversee the process from a strategic level. Decisions in the second level usually follow the completion of the development stage such as concept development, product design, and testing. Decisions at this level are made by the middle to senior managers. The outcomes significantly affect new product development lead time, which is called review decisions. Decisions at the third level are at the operational level of each process stage. Creative and exploratory behavior primarily occurs at this stage called in-stage decisions.

1.1 Motivation

Most decisions in the product development process usually occur in a different uncertainty level of decision making. In the early phases of product development, the level of uncertainty is high because knowledge is limited, the content is unstable, and the available information is insufficient (Legardeur, Boujut & Tiger, 2010; Verganti, 1997). Decision making is generally less uncertain when the time passed because additional information and learning about future stages are increasing (Marschak & Nelson, 1962). However, people and organizations in many companies do not sometimes make a decision as rationally as the prevalent methods within product development (March, 1991). Some companies make a conceptual decision by considering on one direction in the concept development and selecting the previous solution from the earlier project instead of finding a variety solutions and having more discussion (Kihlander, I., & Ritzén, S., 2009). Some companies make a decision in idea selection based on their sense or intuition to make a decision, which is a critical and difficult activity in product development and innovation (Khurana & Rosenthal, 1998; Martinsuo & Poskela, 2011; Sharma, 1999).

Under uncertainty, a decision maker has to find a balance between risks and opportunities before making a decision. A wrong decision can cause the loss of resources, market time, and business opportunity (Ko, 2010). Dysfunction of the decision can be quantified in terms of cost, delay, and quality or greatly increased costs, longer duration, and reduced performance characteristics (Powell & Buede, 2006). Another problem in decision making is collaborative decision-making where different actors have different and often conflicting objectives in the decision-making process because of different domain expertise, information, and knowledge. In other words, decision makers have different objectives and priorities concerning the decision values and alternatives (Jankovic, Zaraté, Bocquet & Le Cardinal, 2009). All of these problems normally occur when decision makers make decisions using heuristic decisions.

Heuristic decisions are simple and efficient rules that are used to make decisions and judgments. They usually focus on one aspect and ignore others to make a decision. These methods provide a good result, but can also lead to systematic deviation from logic, probability or rational choice theory. The resulting errors from the heuristic decisions are called cognitive biases.

Decision making is, however, considered as a skill, which is possible to be trained (Keeney, 2004; Riabacke, 2007). Decision makers can enhance their decision by creating meta-knowledge and awareness of influence factors that impact decision making. Asking a question and ensuring reflection can assist decision makers to be more conscious and increase learning knowledge. These methods rely directly on the decision makers. Decision making can also improve in an indirect way using choice architectures. Different and multiple alternatives to choose when making decisions can increase the success rates (Eisenhardt, 1989; Roozenburg & Eekels, 1995; Tatum, Eberlin, Kottraba & Bradberry, 2003). In a practical situation, decision makers have been seen not going through a process of considering many solutions, but considering one or few solutions that seem to achieve the pursued objectives (López-Mesa, B., & Chakrabarti, A., 2007). For an idea of skill improvement in decision making, there are many researchers who are inspired to investigate models, strategies, and methods to enhance decision making in general activities in product development processes (Kihlander, 2011a, 2011b). An understanding of decision-maker behavior and more specifically, the reason for such behavior, is useful in the advancement of managerial decision making (Dillon, 1998). Skill of decision making is important to be developed in the university and also required in many companies (Wilson, T. T., & Marnewick, A. L., 2018). Even if many techniques to improve decision making are described in researches such as fuzzy logic, decision tree, and pairwise comparison, a method to improve decision-making performance within the product development process is not available (Eriksson, 2009).

1.2 The scope of work and relevant research fields

Decision making is an important skill for the decision maker that defines the direction of a product and processes in product development. Most researches usually focus on decision making in terms of the systematic decision. However, errors in decision making normally appear when heuristic decisions are used to make a decision.

Moreover, many people cannot even notice these errors caused by cognitive biases. This research is, thereby, focusing on heuristic decisions and cognitive biases in the product development process. The researcher aims to improve decision making from heuristic decisions in the product development process. To achieve this objective, knowledge from different research fields such as psychology in decision making, economic behavior, and Product Generation Engineering is required. Figure 1.1 shows relevant research fields and components in this research.

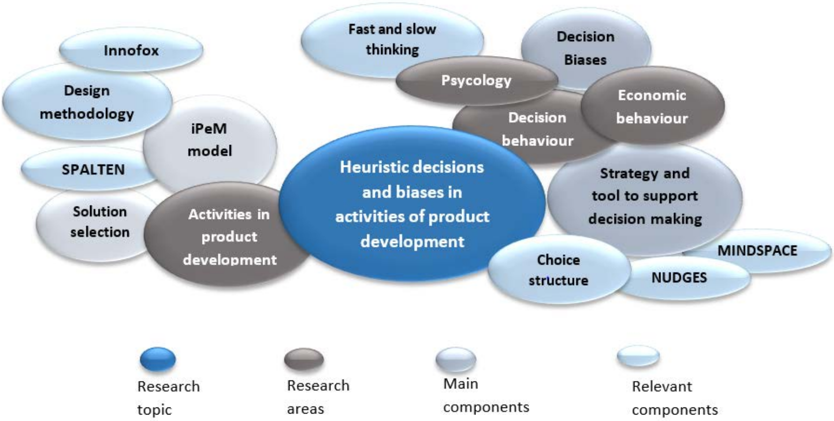


Figure 1.1: Research fields and relevant research areas

1.3 Structure of the thesis

This research starts by investigating a relevance and an important point of decision making in product development. Then a direction of research is defined as described in **Chapter 1**. After that all relevant fundamental knowledge and previous research such as decision making, economic behavior, and PGE by Albers are investigated and reviewed in **Chapter 2**. After investigating and gathering relevant information, the research gap appears. The research objective and research question are then presented in **Chapter 3**. At the end of this chapter, research methodology that explains the procedures of proceeding this research is described. Most information and knowledge in **Chapter 4** indicate different potential factors that relate to the heuristic decisions in product development such as the decision situations, types and characters of heuristic decisions and biases, and design methods to support decision making in product development. These potential factors are then connected and presented in examples. Based on examples and assumptions in **Chapter 4**, four experiments were created and evaluated in **Chapter 5**. **Chapter 6** proposes potential techniques to deal with heuristic decisions and biases from different fields as a de-biasing technique after defining the problems when using heuristic decisions in different activities of the product development processes. This chapter also explains the de-biasing framework that is applied in the product development field.

Chapter 7 illustrates examples of different de-biasing techniques and developed tools that are used to support decision making based on the framework in Chapter 6. **Chapter 8** is the last chapter that summarizes all information and knowledge from this research. Suggestions and future works are also described in this Chapter. An overview of the eight chapters in this thesis is shown in Figure 1.2.

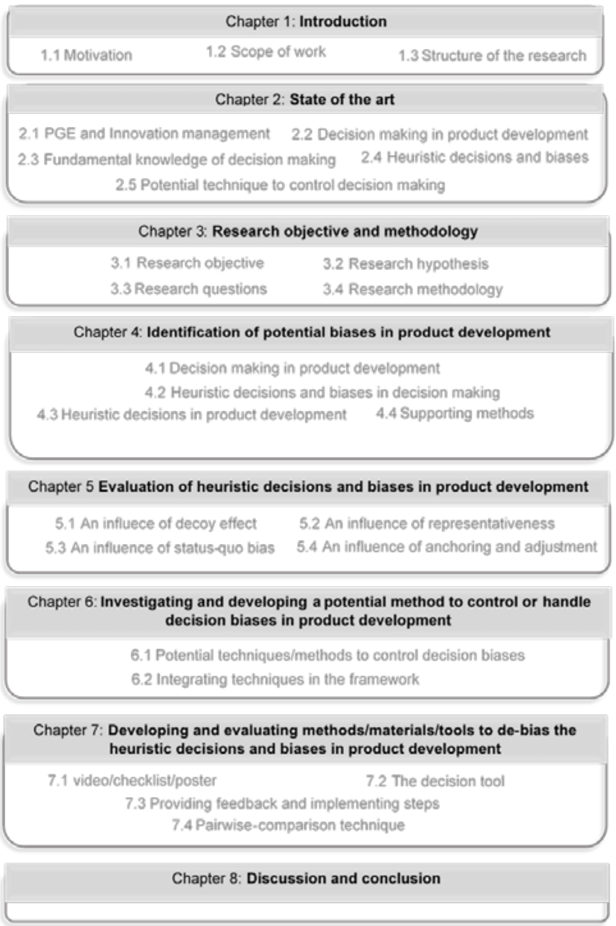


Figure 1.2: Structure of the thesis

1.4 Conclusion

This chapter points out many aspects of decision making in the product development process. Decision making is an important skill for a decision maker to lead the project to be successful. One main key of decision making is the heuristic decisions and cognitive biases. These types of decisions can provide a correct answer and can lead to erroneous decisions. Therefore, good strategies and techniques are required to support decision making to reduce decision errors and project fails. Based on the deficiency points of decision making as described in this chapter, some strategies to support this skill are investigated and required. Understanding and investigating more information about heuristic decisions and biases in product development is the initial step of this thesis.

2 State of the research

This chapter aims to review relevant literature to get the basic knowledge in each topic and a better understanding of heuristic decisions and biases in product development. At the beginning of the chapter the model of PGE - Product Generation Engineering, product development, and innovation management are reviewed to understand the processes and components for product development. Then relevant researches about decision making in this field and in general fields are reviewed to have an overview of decision making in product development. After getting the basic knowledge about product development processes and decision making in the processes, heuristic decisions are then reviewed and focused. Types, characters, and examples from these decisions are investigated from many fields such as economic, politic and engineering. The last part of this chapter illustrates potential techniques to handle decision making from different fields presented in the literature.

2.1 The model of PGE-Product Generation Engineering and innovation management

2.1.1 Description of the model of PGE

Product development consists of the set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product (Ulrich, 2003). Albers proposed the model of the PGE that represents the fundamental observations on the development of new technical products. This model aims to support the developer through the targeted use of methods and processes in various kinds of engineering projects. In the model of PGE, a new product is developed based on existing products and systems called reference systems instead of creating a completely new product due to economical and risk analysis (Albers, Reiß, Bursac, Urbanec & Ludcke, 2014). Therefore, properly working parts and subsystems of more complex systems are maintained as far as possible to minimize technical newness, potential risks and necessary investments e.g. for manufacturing facilities (Albers, A., Bursac, N., & Rapp, S, 2016). The reference system refers to "a system whose elements originate from already existing or already planned socio-technical systems and the associated documentation and are the basis and starting point for the development of the new product generation (Albers, Rapp et al., 2019)". An example of reference system in PGE model is shown in

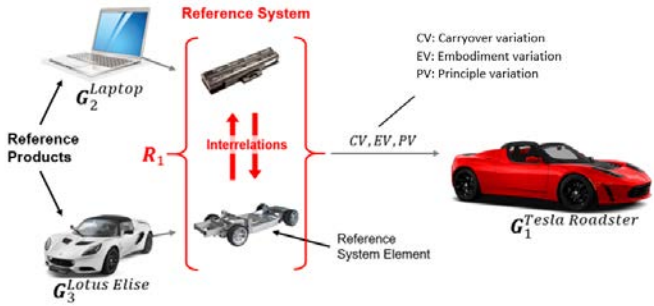


Figure 2.1: PGE model with the reference system based on an example of Tesla Roadster (Albert Albers, Simon Rapp, Nicolas Heitger, Friedrich Wattenberg & Nikola Bursac, 2018)

The reference system consists of various elements that can originate either from partial solutions of the own company of previous generations or from products of other companies or researches. The reference products that have been developed by the same department or in the same company are called internal reference products. On the other hand, the reference products that have been developed from outside the companies are called in external reference product (Albers, Gladysz, Heitger & Wilmsen, 2016).

Albers (Albers, Bursac & Wintergerst, 2015) classified product development into 3 categories based on a concept of product generation engineering. These categories are

- *Principle variation (PV):* defines product development by adapting from products that have similar functions and properties in other contexts or by the systematic search for alternative solution principles
- *Embodiment variation (EV):* is a development with a known solution principle that being carried over from a reference product or the general state of the art and the function-determining properties the most frequent being varied to enhance the competitiveness, performance, and quality of fulfilling the function.
- *Carryover variation (CV):* defines product development by transferring existing solutions of the reference system to new product generation

Principle variation and embodiment variation together form the share of new development. The share of new subsystems regarding the embodiment variation and principle variation, and the types of reference product for a development project can indicate risks and challenges in a development process as shown in Figure 2.2 (Albers, A., Rapp, S., Birk, C., & Bursac, N. Albers, A., Rapp, S., Birk, C., & Bursac, N., 2017).

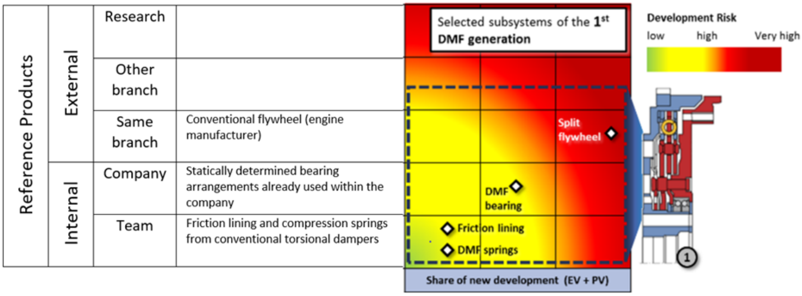


Figure 2.2: Development risks based on the share of new product development and types of reference products (modified from (Albert Albers et al., 2018))

Regarding Figure 2.2 the development risk is higher when a share of new product development or/and a use of external reference products is greater due to technical reasons and available information. The level in the system structure which is affected by variations is another influencing factor that should be added in the framework to analyse the risk development (Albert Albers et al., 2018). This factor is presented in the framework as the third axis to provide a total risk estimation and avoid the underestimation of development risk.

“Innovation” is an important factor for developing a new product and increasing the successful establishment of the invention in the market. Based on Henderson and Clark, product innovation can be described in 4 types: Incremental innovations, Architectural innovations, Modular innovations, and Radial innovations (Schumpeter, 2003). However, types of the product based on innovations can only be retrospectively assessed whether a product was successful in the market and represents an innovation. It is not usually used to describe the direction of product development. The innovation is distinguished from invention by economic significance. The invention will be success on the market when it can satisfy a demand situation and be introduced to the market through suitable marketing activities (Albers, Heimicke, Walter et al., 2018). Figure 2.3 shows the elements of the innovation.

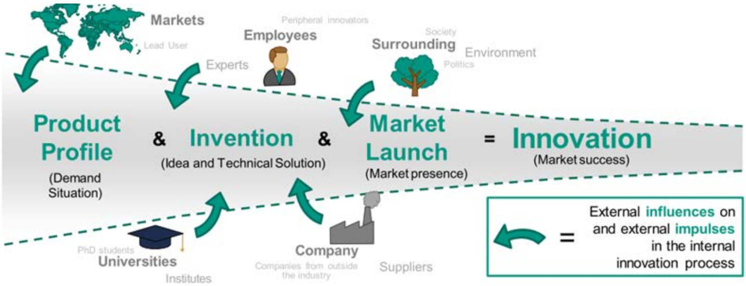


Figure 2.3: The elements of the innovation (Albers, Heimicke, Hirschter et al., 2018)

Product innovation originates from a mix of successful from old design and new ones (Sivaloganathan & Shahin, 1999). Most new products aim to be innovative products, which help companies in being permanently successful in competition. However, only 20% of the components in the new product are newly developed and 40% of them are taken over.

2.1.2 Product development process and the integrated Product engineering Model (iPeM)

A product development process consists of the steps that transform a product concept into the marketable merchandise. There are a number of product development processes and models. Different company departments assign objectives that are necessary for the definition of project objectives to the project team. These departments include marketing, production, innovation, strategy, development, and design (Jankovic, Stal-Le Cardinal & Bocquet, 2010). A new product is generally developed with all activities starting with the identification of a market opportunity and ending with the launch of the product into the market (Artmann, 2009). The product development usually has a review phase and breaks with predefined checkpoints or gates. Each gate consists of clearly prescribed cross-functional and parallel activities. A functional area that the project must pass in order to proceed to the next stage is also described in the gates (Cooper, 1994). Cooper (Cooper, Edgett & Kleinschmidt, 1999) divided the processes for new product development into eight phases as

1) Idea generation phase
2) Idea screening phase
3) Concept development and testing phase
4) Marketing strategy development phase
5) Business analysis phase
6) Product development phase
7) Market testing phase
8) Commercialization phase.

There are many process models in industrial practice. Process models serve as a communication basis for the development of new products and establish an ontology for research on the product development process. Therefore, each model can be focused on different aspects (Tomiyama et al., 2009). The product development process can be seen from an economic view as well as a technical-methodical perspective. The characteristics of different products influence the selection of process models used in development organizations (Eriksson, 2009). Even though many models were designed and developed such as CMMI (Capability Maturity Model Integration) (Crissis, Konrad & Shrum, 2006), V-model VDI 2206 (Möhringer, 2004) or stage-gate (Cooper, 1990); these models are not sufficient to integrate all components including strategies, management, and engineering design. Most modelling approaches focus only on certain points, but do not consider an interaction between activities, requirements, results, and methods. The iPeM was then developed to fill in the gap between process management and engineering design (Albers, Reiss, Bursac & Richter, 2016). This model is based on the ZHO model that is described as a thinking and acting person in the center of an iterative product development process (Albers, A., Ebel, B., & Lohmeyer, Q., 2012).

The iPeM as shown in Figure 2.4 consists of the triple systems of product engineering, which is the system of objectives, the system of objects and the operation system (Ropohl, 1975). The aim regarding the system theory is to transform a system of objectives into the system of objects by the operation system. The system of objectives comprises all explicit targets of a developing product, including their dependencies and boundary conditions within a defined area of interest (i.e. within a system of interest) at a certain time. The system of objects are all results that are generated in the process of product engineering and finally product itself. The operating system is a socio-technical system that is composed of structured activities, methods, and processes as well as the needed resources for the realization, e.g. staff, budget, material, machines, etc.

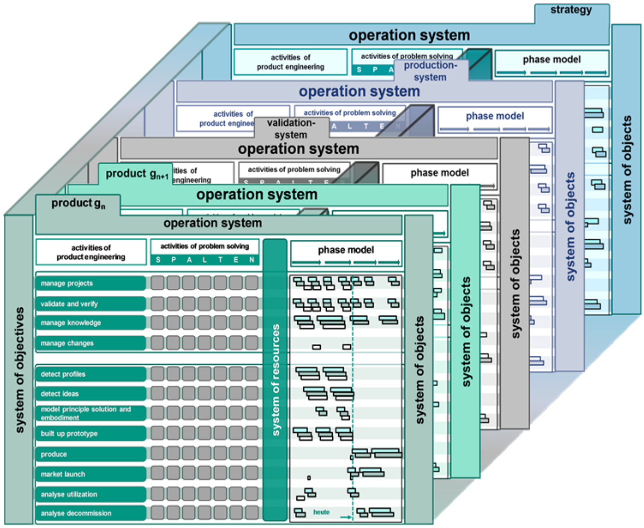


Figure 2.4: The integrated Product engineering Model (iPeM)

The activities of the iPeM are divided into macro and micro activities (Albers, 2010). Micro activities appear iteratively in technical problem solving such as SPALTEN (described in Section 2.1.4), whereas macro activities provide areas of product engineering. The activities of product engineering represent the relevant fields of action of the product developers. The macro activities (Albers & Braun, 2011) are listed without clustering activities in product development. All activities represent the relevant fields of action in product development, which are integrated project management and engineering activities together. Therefore, this model is developed by adding more activities and clustering activities into 2 different clusters of activities.

Cluster 1: "Product engineering activities" consist of detect profiles, detect ideas, model principles solution and embodiment, built up a prototype, produce, market launch, analyze utilization, and analyze decommission. These activities are the core activities of product engineering and are in every development process.

Cluster 2: "Basic activities" consist of manage knowledge, validate and verify, manage knowledge, and manage change. These activities are conducted parallel to all other activities to support, improve, and secure the product development process.

Product strategy, product system, and validation system are also included in this model to describe the product development in an individual layer. Each layer consists of the same structure and activities. Based on this structure, a focused approach is allowed to the respective system in development with a simultaneous integration of the other layers.

2.1.3 Agile System Design (ASD) in Product Development

As mentioned in the previous section, many process models have been proposed and developed such as CMMI, V-model, and stage-gate. Those models are appropriate in a stable environment for plan-driven product development. Within the plan-driven environment, the design planned is constructed from the start to the end of the process. The architecture and design specification has to be complete before implementation begins (Petersen & Wohlin, 2010). Each activity is focused on its own phase such performing programming only in the programming phase. Product development has however uncertain and unstable environments. Therefore, agile approaches are considered to be implemented in processes of product development to support dynamic product development (Heimicke et al., 2018). These approaches originate in software development and are based on the agile manifesto (Fowler & Highsmith, 2001). Agile approaches aim to help facilitate better communication and feedback due to small iteration and customer interaction. The developers can get frequent and fast feedback from the customers. These approaches can also decrease the size and severity of errors emerging from unpredictability. Approaches such as Scrum (Schwaber, 1997) or Design Thinking (Plattner, Meinel & Leifer, 2010) have integrated in to these processes, which serve to operationalize the principles defined in the agile manifesto. However, these approaches such as Scrum work well in the software but cannot achieve all requirements due to physical properties of mechanic systems or in hardware (Schmidt, Weiss & Paetzold, 2017).

A number of agile or hybrid approaches such as agile-stage-gate have been developed to support mechanic system development (Schuh, Dölle, Kantelberg & Menges, 2018; Spreiter, L., Böhmer, A. I., & Lindemann, U., 2018). However, these approaches are only an adaptation of existing approaches from software development and partially fulfill the requirements of mechatronic system development (Heimicke, J., Niever, M., Zimmermann, V., Klippert, M., Marthaler, F., & Albers, A., 2019).

The approach of the ASD-Agile System Design (Albers, Heimicke, Spadinger, Reiss, Breitschuh, Richter, Bursac & Marthaler, 2019b) has been developed to support the entire development process by using the advantages of the agile development and the thought of the PGE-Product Generation Engineering (Albers et al., 2015) in the product creation processes. This approach encourages development teams with structuring, fixed phases and flexible elements in the product development processes. Nine basic principles in ASD are understood as irrefutable and always valid guidelines in product development. These principles can be used to align development activities in order to manage situations adequately in a dynamic and uncertain development context. These basic principles (Albers, Heimicke, Spadinger, Reiss, Breitschuh, Richter, Bursac & Marthaler, 2019a) are in the following:

1) The developer is the centre of product development
2) Each product development process is unique and individual
3) Agile, situation and demand-oriented combination of structuring and flexible elements
4) Each processing element can be located in the system triple and each activity is based on the fundamental operator's analysis and synthesis
5) All activities in product engineering are to be understood as a problem-solving process
6) Each product is developed on the basis of references
7) Product profiles, invention, and business model form the necessary components of the innovation process
8) Early and continuous validation serves the purpose of continuous comparison between the problem and its solution
9) For situation and demand-oriented support in every development project, methods and processes must be scalable.

Effects of core principles of ASD are explicitly illustrated to be understanding of the individual core principles of ASD, which made it possible to create the network matrix. Based on this matrix, a factor that has an influence on the agility of an operation system is set to a core ASD principle if both elements serve at least one common effect. The general relevance of a principle can be estimated by counting the number of factors that are assigned to each individual ASD core principle. When a principle has been assigned a particularly large number of factors, that principle has an influence on the agile capabilities of the operation system in broad application cases (Albers, A., Heimicke, J., and Trost, S., 2020). In the research, the first principle "the developer is the centre of product development" has the greatest influence on the success of a development project and contains the greatest implications for the other 8 principles. That means this principle should be implemented together with other principles in most cases. Even though all principles are connected with each other, but the strength of the connection varies. Figure 2.5 shows implications and interactions of the ASD core principles based on an analysis from 12 real development projects.

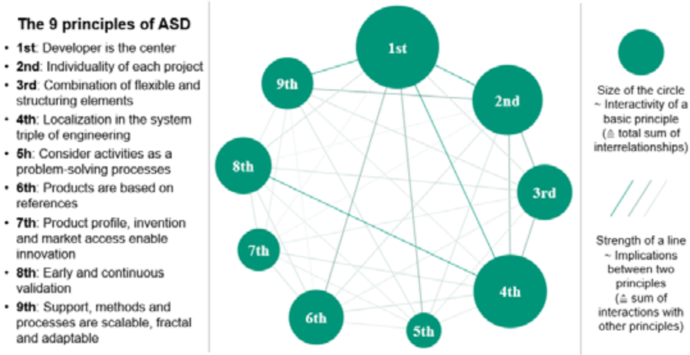


Figure 2.5: Implications and interactions of the ASD core principles (Albers, A., Heimicke, J., and Trost, S., 2020)

2.1.4 Problem-solving method and decision making

In product development, problems can be occurred such as sudden component failure of a prototype in the testing process, which requires a solving method to find a solution. A problem-solving process can then represent a product development process regarding a concept idea that the unsatisfactory current situation originates the requirement. Even though many problem-solving methods are proposed such as TOTE-scheme, 8D-Method, etc, these methods are highly complex to deal with unstructured and intuitive problem that leads to low acceptance in practices.

SPALTEN developed by Albers is one of a method for a cycle of problem-solving activities in a specific structure or sequence, which is a part of the operating system in the iPeM model. SPALTEN was developed as an acronym, which helps the problem solver to notice the steps in a logical sequence. An acronym is remembered as one single chunk that help reduces mental workload necessary for structuring the problem solving process. The chunk is a collection of basic familiar units that haven been grouped together and stored in a person's memory, which improves short-term retention of material and bypasses the limited capacity of working memory. SPALTEN then overcomes the cognitive restrictions of working memory, which leads an achievement of applying it for a problem-solving situation. SPALTEN describes a universal approach, which is not limited to special problems and can be adapted according to constraints and complexity degree to the problem formulation. Because SPALTEN is universal and can be used in different abstraction levels, it is possible to be applied during the entire product development process just as well as during the several phases of the product development process and during the several activities which are operated during these phases. Problem-solving is supported by the SPALTEN methodology by the integration of a huge number of methods (Albers, Reiß, Bursac & Breitschuh, 2016).

Seven working steps of problem-solving activities in SPALTEN are used to solve different complexity of problems. These steps are situation analysis (S), problem containment (P), detection of alternative solutions (A), selection of solutions (L), analysis of consequences (T), deciding and implementing (E) and recapitulation and learning (N) (Albers, Reiß et al., 2016). An explanation of each step and connections between each step are shown in Figure 2.6.

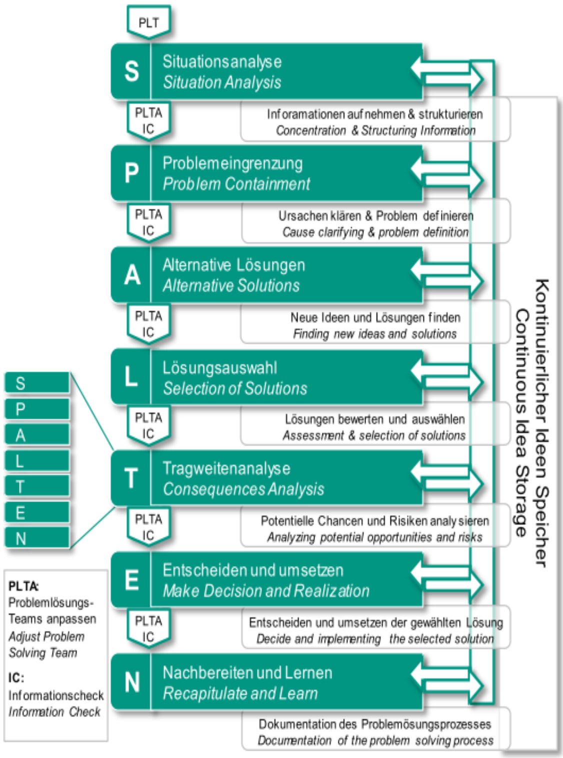


Figure 2.6: The SPALTEN problem-solving method from Albers (Albers, Reiß et al., 2016)

One important factor to solve problems is decision making. Decision or choice made about the same decision problem will vary between individuals and across different contexts. This behavior can be explained by the mental model of a problem (Schoemaker & Russo, 2001). Information about the decision problem and the context of decision problems (such as time constraints and emotional aspects) are components in this model. Different ways to perceive, organize and interpret information can lead to different individual decisions. Two individuals who might be presented with the same problem stimulus might actually be solving different 'mental' problems (Beresford & Sloper, 2008).

2.1.5 Factors for successful in product development

There are many models and activities that are described and developed to support the product development process. Lindemann described 3 key factors for successful products, which are 1) create customer value, 2) short development cycles, and 3) competitive market price (Lindemann, 2006). Murphy also proposed 2 factors that play a major role in product success, which are the quality of execution of front end activities and the creation of a well-defined product prior to development (Steven A. Murphy and Vinod Kumar, 1997). All activities in the front end stage mean all activities starting from formulating a concept of product to be developed until deciding whether or not to invest resources in the further development of an idea. Even though the success in product development is defined in different aspects, the most important factor required in all aspects is a good decision. Eriksson then proposed to view product development as a decision production system (Eriksson, 2009). It is the main component to lead product development in different directions.

2.2 Decision making in product development

2.2.1 Description of decision making and decision behavior in product development

Decision making is an important activity in product development to lead a project to fail or success. It is often described as a problem-solving activity where a present state of the situation is described, as well as the future preferred state (Hazelrigg, 1996). Decision making is normally considered in a product design activity and an easy front end stage, which is a "what-if" type (Jönsson, 2004) to make an assumption for the question For example, what if the customers required more function for health care in an automotive industry? Which function should be developed and implemented in the automotive system? In the early phase of product development, information to support decision making is often insufficient. Decision makers may have the flexibility to postpone a part of the decision until additional information becomes available. This new information can then be used to update the initial probability estimates about the state of nature so that the final decision is based upon more accurate data (Artmann, 2009).

However, the limited time in a project and the complex set of requirements can lead the decision makers to struggle to find one solution that complies with all requirements. Most often they achieve something that can be considered a satisfying solution, instead of finding an optimized solution (Kihlander & Ritzén, 2012). Sometimes decision makers operate the decision in a surveillance mode rather than a problem-solving mode. A problem is not recognized until the solution is defined. For example, decision makers decided to develop the product based on requirements from a specific group of customers instead of general customers. This solution is raised without defining the problem or question. Decision makers examine their environments and observe what is going on. Then rules and solutions are copied and applied from others instead of solving problems (March, 1991). When reviewing the literature of decision-making in product development, including its influencing factors, three categorizations can be distinguished: decision-making procedures (activities) (Gidel, Gautier & Duchamp, 2005), decision making uncertainty (Busby, 2001), and decision-making environment (Simon & MARCH, 1976).

Patterns of decisions in design content are classified into 5 patterns: leap, loop, cycle, sequence, and meta-process (Kihlander, 2011a). *Leap* is a fragmented process. There is no clear common goal in the group, and deficient decisions have to be revised. *Loop* is described as a reiteration. A long-time period for a decision is required. Results from this pattern are also poor. *A cycle* is the reiteration of partial sequences of process steps. A long decision process is required. *A sequence* is a rational and step-by-step pattern. The decision process is fast and progresses in the problem-solving activity. *Meta-processes* also progress in the problem-solving activity and require moderator guides. In the product development process model, the actual decision-making does not often have patterns of leaps, loops, and cycles (Eriksson, 2009).

Decisions based on a system of New Product Development (NPD) are different (McCarthy et al., 2006a). NPD can be described as a process including many generic decision points. Urban and Hauser (Urban & Hauser, 1980) suggested five steps of decision process for NPD, which are opportunity identification, design, testing introduction and life cycle management. Each step is summarized and shown in Figure 2.7.

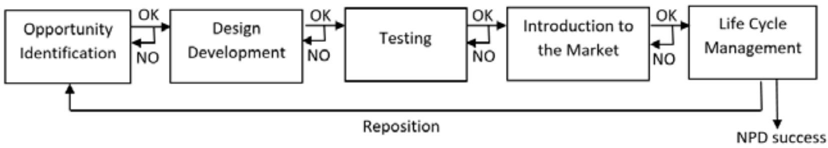


Figure 2.7: New Product Development (NPD) process (Matheson, Matheson & Matheson, 1998)

This system can be described by three different frameworks: linear, recursive, and chaotic. In the linear framework, the effect of decision on the project would be the one anticipated such as the improvement of a product feature regarding customer feedback. The system of a cyclical path is consistent with the recursive framework. It will give feedback and reuse similar and familiar decisions from previous and comparable projects. Decisions in the chaotic system create a potential change in trajectory direction. Decision outcomes can be amplified, producing paths that lead to good or bad process performance. The probability and degree of trajectory change will depend on the stage and the level of the NPD - New Product Development process (McCarthy et al., 2006a).

The decision process based on the environment can be classified into 2 approaches: the outside-in approach and the inside-out approach (Summers & Scherpereel, 2008). *The outside-in* approach explicitly models decisions by seeking the best solutions and pushing the solution into a business process. This approach embraces complexity, gives decision makers many degrees of freedom, and adjusts to mistakes. *The inside-out* approach uses a pull mechanism to identify problems. The problems are then resolved by modifying the system to constrain decisions. The approach constrains the decisions with rules, tools, and policies that guide work. The inside-out approach seeks consistency. Decisions proceed under controllable and uncontrollable environments. Business context, such as decision tools and processes, culture and product structure, is described as a controllable environment. Environment context, such as competition, customer surveys, and legal considerations, is an uncontrollable environment. Figure 2.8 shows the framework of decision making.

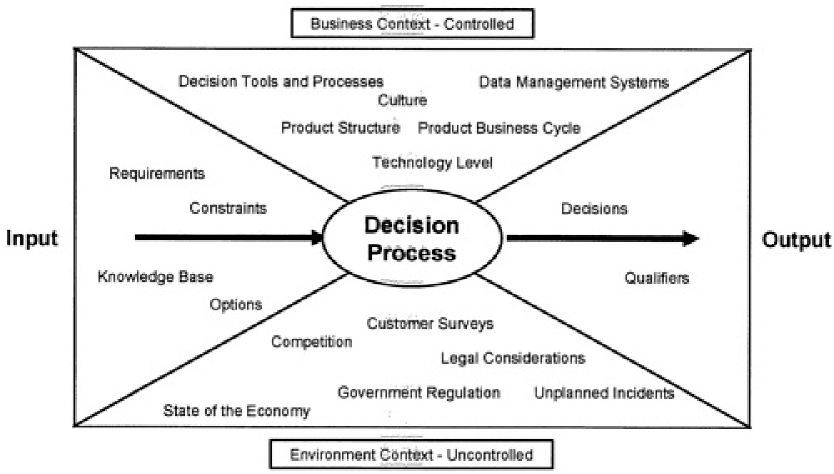


Figure 2.8: Framework of decision making in engineering design (National Research Council Committee on Theoretical Foundations for Decision Making in Engineering Design, 2001)

2.2.2 Different perspectives about decision making

Decision making in product development can be described in different meanings and perspectives regarding different departments. Table 2.1 (Seram, 2013) describes different characters of the decisions in product development regarding different departments.

Table 2.1: Different meaning of decision making based on different departments in product development

	Marketing	Engineering design	Operation management	Organization
Perspective on product	A product is a bundle of attributes	A product is a complex assembly of interacting components	A product is a sequence of development / process steps	A product is an artifact resulting from an organizational process
Typical performance metrics	"fit with market" Market share , customer utility, profit	" form and function" Technical performance, innovativeness, cost	"efficiency" total cost several level lead time capacity utilization	" project success"
Dominant representation al paradigm	Customer utility as a function of product attributes	Geometric models, Parametric models of technical performance	Process flow diagram, Parametric models of process performance	No dominant paradigm, organizational network some time used
Example decision variables	Product attribute levels, price	Product size, shape, configuration, function ,dimension	Development process sequence and schedule point of differentiation in production process	Product development team structure, incentives
Critical success factors	Product positioning and pricing, collecting and meeting customer needs	Creative concept and configuration, performance optimization	Supplier and material selection, design of production sequence	Organizational alignment, team characteristics

Even decisions are described and made in different ways; all decisions revolve around groups of common issues. The groups include *product concept, architecture, configuration procurement, and project schedule (Powell & Buede, 2006)*. These groups are necessary for the project manager to make decisions with alternatives, optimization of design, planning and reviewing meeting, and go/no go or revise (Eriksson, 2009).

The decision-making model can be defined in 4 views, which are the objective view, the process view, the environment view, and the transformation view (Jankovic et al., 2010). *The objective views* describe the objectives in the collaborative decision-making and the inter-relationships that influence their definition. *The process views* explain collaborative decision-making in order to assure the quality of the decision. *The environment views* concern the product development process that can be seen as enterprise know-how. *The transformation views* represent a follow up of different evolution states in collaborative decision-making.

2.2.3 Factors/elements of decision making in product development

There are many factors related to the decision-making process, which are separated into 3 groups: environment and structure, enablers of decisions, and procedures. The factors of each group are shown in Table 2.2 (Eriksson, 2009).

Table 2.2: Three groups of factors that are related to the decision-making process (Eriksson, 2009)

Environment and struucture	Enables of decisions	Procedures
An overview of decisions	Decision Criteria	Scope management
Competitors	Tradeoffs	Planning and control
Functional integration	Commitments	Manning
Processes	Alternatives	Strategies
Structures	Intuition	Decision procedure
Authority	Rationality	Coordination
Stakeholders	Decision premises	Change management
Decision culture	Goals	Objective creep
Politics	Market need	Information flows
Roles	Information	Resource management
Uncertainty		Decision methods
		Requirement management
		Consequence analysis

Criteria for the decision makers in product development can be described in many ways. A big group of criteria consists of product, marketing, and financial criteria. These criteria cause 3 questions (Ronkainen, 1985):

1) Is there a market for the concept?
2) Can the concept be transformed into a concrete product?
3) Can the concrete product be manufactured and marketed profitably?

Not only the criterion to make a decision is important, but the process is as well. Eriksson (Eriksson, 2009) defines 9 important elements of collaborative decision-making, which are:

1) The development process
2) The structure of the process
3) The performance of decisions
4) The framing decisions
5) The organization
6) Communication in order to achieve objects, goals, alternatives and to manage tradeoffs
7) Individual actors and their performances, objectives, and judgment
8) Methods/tools
9) The product/delivery/output.

Joakim (Joakim et al., 2007) proposed 10 common factors that affect the decision-making process.

1) *Handling of requirement*: quality of handling requirement affects to exceed project time (cost) and budget.
2) *Experience of projects*: insufficient experience in product development can lead to an inaccurate estimation of the necessary amount of hours in offers to customers.
3) *Organizational aspects:* fuzzy organization causes the engineering to work in an unplanned environment across multiple projects
4) *Project management*: managers can influence the decision-making of workers by 4 actions:

- influencing specific decisions such as deciding personally, participating in decision group, and affecting other's decision deliberations
- supervising decision routines
- shaping decision practices
- providing decision resources (Eriksson, 2009), Decision criteria or risk assessments are not defined in a company.

5) *Top management*: top management did not fully trust the project personnel, which results in unnecessary waiting for decision making.
6*) Knowledge*: management's knowledge of process implementation and communicating common goals and strategy for product development projects is necessary.
7) *Risk management:* an ability to assess risks in projects due to the experience-based checklist is important to define the success of the project.
8) *Information systems*: IT solution for managing product information is required
9) *Communication*: informal decisions regarding critical issues that were taken outside the formal meeting were not always communicated
10) *Change management*: changing management requires (negative direction) too much time and effort to develop a complete requirement specification.

2.2.4 Systematic methods and models to assist decision making

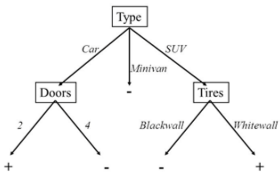
There are many decision tools and models that are applied to support decision making in product development. Seram and Niromi summarized potential methods for different purposes in product development as shown in Table 2.3 (Seram, 2013).

Table 2.3: Decision-making models and methods to support different purposes of product development (Seram, 2013)

Purpose	Decision making model/tools developed
Idea screening	1. Fuzzy synthetic evaluation method (FSEM) based on fuzzy set theory (Ko, 2010)
Product concept evaluation	1. Extended house of quality & mixed integer non-linear programming considering product life cycle factors and resource constrains (Shin, Jun, Kiritsis & Xirouchakis, 2011) 2. Monte Carlo simulation 3. Analytical network process 4. Pugh's evaluation matrix
To identify customer requirements	1. QFD (quality function deployment) to identify the customer attributes and transfer to engineering attributes 2. AHP (analytic hierarchy process) 3. (Fuzzy analytic hierarchy process) 4. AHP and Fuzzy logic to determine target values of product characteristics 5. Non liner mathematical programme to determine engineering characteristics under concerns of cost and life cycle constraints 6. FQFD (Fuzzy quality function deployment) to determine the target values of design characteristics (Lin, Wang, Chen & Chang, 2008)
Design for Manufacture/ assembly	1. Fuzzy logic 2. Multiple attribute decision making (MADM) 3. Fuzzy Multiple attribute decision making (FMADM) 4. MADM & activity based costing (ABC)
Suitable design solutions	1. TOPSIS 2. AHP & TOPSIS(Lin et al., 2008) 3. DM (decision matrix) 4. Robust design (RD) 5. value analysis/engineering (VA/VE) 6. design for X (DFX) 7. axiomatic design (AD) 8. Integrating –QFD & Value analysis (VA) & data envelopment analysis (DEA) (Cariaga, El-Diraby & Osman, 2007)
Supplier evaluation/selection	1. Data envelopment analysis (DEA)- Mainly focuses on the system efficiency 2. Mathematical programming models 3. Analytic hierarchy process (AHP) 4. Cased based reasoning (CBR) 5. Analytic network process (ANP) 6. Fuzzy set theory 7. Simple multi-attribute rating technique (SMART) 8. Generic algorithm

Purpose	**Decision making model/tools developed**
	9. Criteria based decision making methods (ELECTRE, PROMETHEE)
Cost management	1. Integrating- QFD, value engineering (VE) & target costing- mathematical programming approach (Jariri & ZEGORDI, 2008)

Instead of objectives in product development, methods are selected to support decision making at different levels in the product development organization (Guideline, 1987). On an operational level, the engineer has different methods to support the clarification and the structuring of the design tasks within a range of design stages in order to make decisions. Examples of design methods are brainstorming, cost-benefit analysis, use-value analysis, decision tree analysis, and decision criteria matrix. Figure 2.9 shows examples of decision tree and decision criteria matrix.



Decision tree

Criteria	Weighting	OPTIONS					
		Option 1		Option 2		Option 3	
		Score	Total	Score	Total	Score	Total
Criteria 1	1	1	1	5	5	5	5
Criteria 2	2	2	4	4	8	5	10
Criteria 3	3	3	9	3	9	5	15
Criteria 4	4	4	16	2	8	5	20
Criteria 5	5	5	25	1	5	5	25
	TOTAL:		55		35		75

Decison criteria matrix

Figure 2.9: Examples of design methods on an operational level such as Decison tree (Rajesh S. Brid, 2020) and Decision criteria matrix (*Expert Program Management,* 2020)

A decision matrix is usually used by identifying criteria for comparison, weighting the criteria, selecting alternatives to be compared, and generating and computing a total score. It can be used in many forms (Kihlander, I., & Ritzén, S., 2009). A well-known example is “Pugh’s matrix” (Burge, 2011) as shown in Figure 2.10.

	Design Concept A	Design Concept B	Design Concept C	Design Concept D	Design Concept BC	Design Concept BD
Criteria 1	S	+	S	+	+	+
Criteria 2	S	-	S	+	S	+
Criteria 3	S	S	S	+	S	+
Criteria 4	S	-	+	+	+	+
Criteria 5	S	-	+	+	+	+
Criteria 6	S	-	S	-	S	-
Criteria 7	S	+	S	-	+	+
Criteria 8	S	+	S	-	+	+
Criteria 9	S	-	S	-	S	-
Criteria 10	S	S	-	S	S	S
TOTAL +	0	3	2	5	5	7
TOTAL -	0	5	1	4	0	2
TOTAL SCORE	0	-2	1	1	5	5

- better than the baseline a "+" is entered in the appropriate cell
- worse than the baseline a "-" is entered in the appropriate cell
- the same than the baseline a "S" is entered in the appropriate cell

Figure 2.10: The example of Pugh's matrix (Burge, 2011)

On the project level, the project manager usually has methods and techniques for structuring activities and the management of project stakeholders, resources, and costs such as are a stage-gate process, deficiency report, enterprise resource planning, interface chart, and recovery planning wave. However, existing methods and tools are often too generic in nature, which are not suitable for the project manager's task (Wenell, 2001).

Oliveira (Oliveira, Rozenfeld, Phaal & Probert, 2015) proposed the *DeBK method* to make a better decision when good knowledge of project information is available. This method comprises of 4 activities, which are

1) Evaluation of the level of knowledge of information
2) Evaluation of the importance of decision criteria
3) Calculation of the applicability measure of decision criteria
4) Assessment of the decision-making process

This technique requires 3 core components: a list of project information, a list of decision criteria, and a matrix linking decision between them.

Fuzzy logic is another well-known method to support decision making (Seram, 2013). There are many applied methods developed based on fuzzy logic. This logic allow uncertain and imprecise systems of the real world to be captured through the use of linguistic terms. Therefore, computers can simulate the human thought processes.

Analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. This method derives ratio scales from paired comparisons and allow some small inconsistency in judgment (Oliveira et al., 2015). This method helps to capture both subjective and objective aspects of a decision and is useful for checking the consistency of the decision maker's evaluations.

2.2.5 Problems in decision making and suggestion

Though there are many methods to support decision making, these methods are rarely used in the industry (Kihlander, 2011a; Reiss, Albers & Bursac, 2017). The needs of industrial operations are not achieved by the available supporting methods or simply bad practices in the companies because limited knowledge and insufficient information are available early in product development projects. Methods are then rarely applied for decision making. While there is more potential to influence the product early in the development process, there is less knowledge and information regarding the design problem (Kihlander & Ritzén, 2012). Methods such as QFD, FTA, FMEA, and Decision Analysis aim to encourage our ability to understand relationships and dynamic situations such as managing the collaborative decision-making process and organization culture. However, these methods are considered to be too complex (Eriksson, 2009). Many methodologies require large quantities of data that are either unavailable or difficult to obtain (Frost, 1999). Template or requirements in methods are also difficult to be identified, such as a decision matrix. A number of alternatives and a number of criteria have to be listed in a matrix form, which requires information from experts. What criteria should be used is not directed in the template and was only occasionally given by the overall development projects. A function for weighting the evaluation criteria is included in the template but was experienced by the experts that is difficult to extract and use. This had the result that the weighting function in the template was used in different ways, and sometimes not at all (Kihlander & Ritzén, 2012). Moreover, engineers or users have no time or available expertise about how to use and integrate the methods in product development (Birkhofer, H., Jänsch, J., & Kloberdanz, H., 2005; López-Mesa & Bylund, 2011).

Albers and Reiss realized the problems of method acceptance, so then they developed the Innofox method recommendation app (Albers, A., Reiß, N., Bursac, N., Walter, B., & Gladysz, B., 2015) that is used for recommending development methods in accordance with the respective specific situations by linking the product engineering process (PEP) with the supporting methods (Reiss et al., 2017). This app is developed based on the iPeM. The method database that consists of more than 100 methods is integrated in this app. Recommended methods are proposed based on the possibility of evaluating situations either directly through activities in the iPeM or through the interactive question dialog as shown in Figure 2.11.

Figure 2.11: Innofox method recommendation app (Albers, A., Reiß, N., Bursac, N., Walter, B., & Gladysz, B., 2015)

Apart from application as mentioned above, 4 approaches are proposed by Geis to develop a model in Figure 2.12 for implementation of the method into daily practice (Geis, C., Bierhals, R., Schuster, I., Badke-Schaub, P., & Birkhofer, H., 2008).

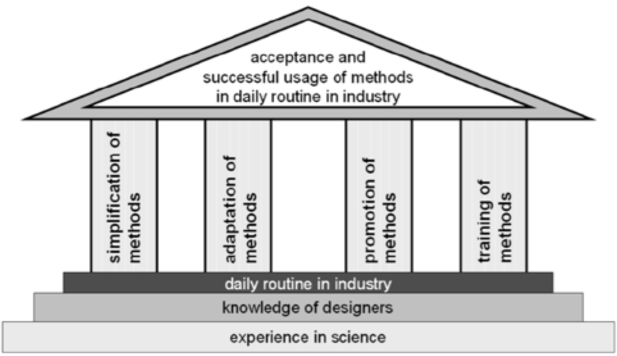


Figure 2.12: The model for successful development, transfer and usage of methods in industry (Geis, C., Bierhals, R., Schuster, I., Badke-Schaub, P., & Birkhofer, H., 2008)

1) *Simplification of methods* (most methods are still too theoretical for practical use).
2) *Adaptation of methods* (methods are often designed to support designers in specific situations, not fitting into the daily routines)
3) *Promotion of methods* (methods must be prepared for change, and further a culture-positive towards methods should be established).
4) *Development and implementation of appropriate training on design methods* (designers do not spontaneously start using methods, methods have to be taught at

In many models, the more a model is complex, with many parameters, the greater the variance, creating confusion between noise and signal and failing to predict accurately, especially for smaller sets of data, or when less relevant parameters are included in a model. This is the reason that it might be better to prune a model and ignore on purpose some of the available data, in order to reduce variance. This feature has been defined as the **less-is-more effect:** "there is an inverse-U-shaped relation between the level of accuracy and amount of information, computation or time" as shown in Figure 2.13 (Atanasiu, 2017).

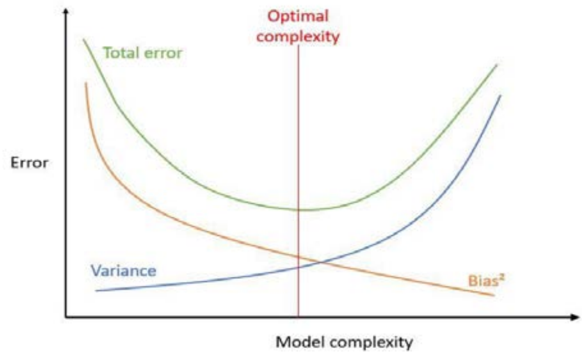


Figure 2.13: An inverse-U-shaped relation that is used to show the less-is-more effect (Radu Fotolescu, 2017)

Less information and computation can sometimes lead to higher accuracy, and in these situations, the mind does not need to make trade-offs. Here, a less-is-more effect holds. The simple heuristics can be more accurate than complex procedures. It is one of the major discoveries of the last decades (Gigerenzer, 2008). It is important for the decision maker to identify, categorize decisions, and figure it out when the decision is made in the organization (Blenko, Mankins & Rogers, 2010). Even rational thinking is usually applied in the decision making for the front end gate to avoid wrong decision making, intuitive decision makers are more likely to continue the project that should be stopped because of a conditional on committing to the project at the idea gate (Eliëns, Eling, Gelper & Langerak, 2018).

Three relevant factors that can lead decision making to go in the wrong direction are described (Brown, 2000):

1) ***The presence of inappropriate self-interest.*** Bias from the emotional importance that we place on the information, which in turn makes us ready to perceive the patterns we want to see.
2) ***The presence of distorting attachments.*** Decision makers can be attached to people, places, and things. Then these bonds can affect the judgments we form about both the situation we face and the appropriate actions to take.
3) ***The presence of misleading memories.*** These are memories that seem relevant and comparable to the current situation but lead our thinking down the wrong path. Decision makers do not usually consider all relevant information and not appraising the full range of options available

Poveda and García defined 3 elements that lead an ill-structured decision model, which are task objectives and outcomes, changes in decision outcomes, and uncertainty (Poveda-Bautista, R., & Pastor-Ferrando, J. P., 2007). Decision making in product development is usually made in uncertainty situations, which comes from the market, technical, resource and schedule (Artmann, 2009). The degree of uncertainty depends on aspects like the degree of innovation, selected technology, project duration, and characteristics of the target market (Dahan & Mendelson, 2001; Schroder & Jetter, 2003). Raanan (Lipshitz & Strauss, 1997) investigate a resource of uncertainty from 102 self-reports of decision making under uncertainty with an inclusive method of classifying conceptualization of uncertainty and coping mechanisms developed from the decision-making literature. The result shows 44% of the cases come from inadequate understanding, 21% of the cases are incomplete information, and 25% of the cases are caused by undifferentiated alternatives.

However, these uncertainties can be responded by (Lipshitz & Strauss, 1997)

- Reducing uncertainty from collecting additional information
- Assumption-based reasoning
- Weighing the pros and cons of competing alternatives
- Suppressing uncertainty by including tactics of denial and rationalization
- Forecasting.

Even though many methods were proposed to deal with decision making in different situations as described above, there are many challenges in the concept of decision-making processes. These challenges include (Kihlander, 2011a):

- To develop alternative solutions, instead of iterating one main-track solution
- To compare properly alternatives
- To achieve compatibility before completeness

2.3 General knowledge of decision making

2.3.1 Meaning and field of studies

Decision making is a process to identify and choose a solution from alternatives based on criteria and personal preference. There are many research fields that study decision making (Stingl & Geraldi, 2017). A Reductionist studies decision making in terms of a rational decision, deviation from the norm, and the bias or error. This research looks for the roots of irrational decisions by building on the experimental approach of psychology and cognitive science. A Pluralist studies a good decision based on rational reasoning. Researches in this field focus on the roots of inaccurate forecasts and sub-optimal decisions. Researchers usually review about the impact of deviating interests and opportunistic behavior. A Contextualist uses the convergence of sense and meaning as an enabler for decisions that are perceived as right or successful. Literature in this group is about analyzing decisions as to the result of a sense-making process.

Even if many researchers try to study and understand decision making from different perspectives, it comes from the same resource that is the human brain. The human brain uses knowledge and experience to develop an expectancy or cognitive representation that is called a cognitive map. Information and knowledge in this map are not applied immediately, but only used and tested later when a stimulus occurs. Our brain will summarize and analyze the situation when a judgment is required to identify important attributes (Albar, 2013). The main area, to process and involve decision making, is all areas of the prefrontal cortex (PFC) (Gutnik, Hakimzada, Yoskowitz & Patel, 2006). Somatic markers are the mechanism in the brain that are relevant to emotions and influence subsequent decision-making. The mechanism will be adjusted based on a specific thought or behavior, which can also produce bias in a maladaptive situation (Beresford & Sloper, 2008).

A dual-system theoretical framework by Daniel Kahneman is proposed (Beresford & Sloper, 2008) to explain why our judgments and decisions often do not follow formal notions of rationality.

- ***System 1 thinking*** is selected when cognitive load is high or time is short. Intuitive, automatic, experience-based, and relatively unconscious are used in the thinking process. This thinking comes from mental content that is easily accessible, which is called hot affect or cognition. It involves a heightened response to stimuli that are driven by emotion.

- ***System 2 thinking*** is used in situations either where the individual cannot rely on past experience or respect for future events. This system is more reflective, controlled, deliberative, and analytical. Mental operation is supervised and controlled, which is called cold effect or cognition, unemotionally aroused into action, making fully informed, controlled, and considered choices.

These brain systems interact with each other to revisit standard paradigms of choice, propose choices that fit the behavioral data better, and offer testable predictions (Brocas & Carrillo, 2014). Neuroeconomic tries to use the benefit of these systems thinking in the economic field. They fuse to theories, methods, and principles of psychology, economics, and neuroscience into a choice theory (Gutnik et al., 2006).

2.3.2 Types of decision making

Decision making are described in 3 types: normative, descriptive, and prescriptive.

1) ***A normative type*** explains what people should do (Dillon, 1998) and how a rational individual should behave (Gutnik et al., 2006). Cognitive limitations in this group are seen as systematic biases (Eriksson, 2009). The normative type of decision is viewed as unrealistic and ideal of decision making. This model can be viewed as a basis for discussion about the ideal of decision-making (Bakka, Fivelsdal & Lindkvist, 1993). This model is shown in Figure 2.14.

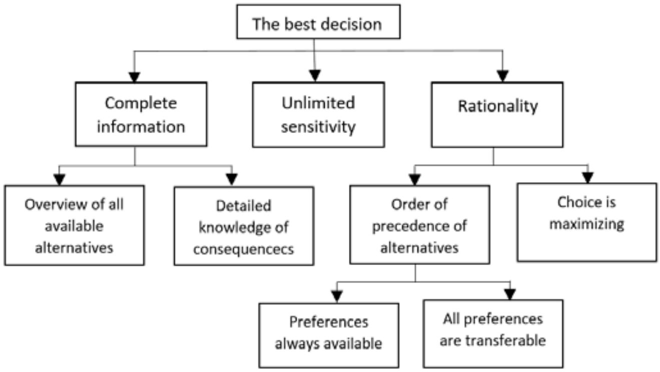


Figure 2.14: The ideal decision-making model in the normative type (Bakka et al., 1993)

2) ***A descriptive type*** tries to characterize how an individual does behave and what people actually do or have done. Cognitive limitations in this group are seen as human cognitive errors (Eriksson, 2009). The descriptive model of decision making can be studied regarding 5 models: econological model, bounded rationality model, organization model, implicit favorite model, and political/competitive model (Bahl & Hunt, 1984).

- *An econological model*: this model assumes that individuals are fully informed, economically rational maximizers and that decision-making process through a series of analytic steps
- *A bounded rationality model*: this model recognizes several limitations on information processing capabilities, time available, and the importance of decisions
- *An organization model*: the organization is viewed in terms of internal coalitions, an organization unit can define its own priorities, goals, and objectives.
- *An implicit favorite model*: the decision maker in this model identifies a favorite alternative on the basis of one or two primary characteristics. Information and criteria factors occur to produce a biased decision rule.
- *A political/competitive model*: most decisions are in the strategic and policy level, which are considered to be made in relation to political constraints, aspiration, and interaction.

*3) **A prescriptive study***, which is concerned with the derivation of optical strategies when a decision maker is faced with several decision alternatives and uncertainty situations (Artmann, 2009). This group of decision making describes what people should and can do (Dillon, 1998), how to behave under our own cognitive and other limitations (Gutnik et al., 2006). Decision making in this group is a process of identifying the need for a decision, defining the problem, specifying the goal and objective, developing alternatives, evaluating those alternatives and making the decision referred to as the Canonical model (Eriksson, 2009).

Theories of decision are also described in different ways. *Classical decision theory (CDT)* identifies decision making by choosing a course of action among a fixed set of alternatives with a specific goal in mind. Options or courses of action, belief and expectancies of the options in achieving the goal, and outcome expectancies in negative or positive are components of a decision (Gutnik et al., 2006). Another theory is *the information-processing approach*, which focuses on how people choose between alternatives when none is clearly the best option. *Prospect theory* is another well-known theory that explains decision making involving risk or uncertainty. The theory of planned behaviors describes a relationship between attitudes and behaviors in the context of making choices (Beresford & Sloper, 2008).

2.3.3 Relevant factors of decision making and processes

Decision making can be influenced by many such as a decision maker's behavior and environments. Dietrich (Dietrich, 2010) proposed 6 factors that influence decision making caused by decision makers. These factors are

- Past experience
- A variety of cognitive biases
- An escalation of commitment
- Sunk outcomes,
- Individual differences
- Routine activity.

Eriksson (Eriksson, 2009) defined relevant factors of decision making in a different way. He focused on environments to form decision making, which are expressed by 8 factors:

- Goal
- Alternative
- Decision-making procedure
- Criteria
- Consequence analysis

- Uncertainty
- Tradeoffs
- Information

Decision making can be described in terms of choice evaluation, which are possibly influenced by 4 factors (Gutnik et al., 2006):

- The emotional
- Socio-cultural
- Environmental
- Neurophysiological

The risk and benefit of the decision are evaluated by an individual's emotional, cognitive state and temporal focus. Acquisti (Acquisti, 2009) poposed 6 factors that can influence decision making.

- Inconsistent preferences and frames of judgment: different situations of decision making can lead to a decision maker's preference in different ways.
- Opposing or contradictory needs from different resources: there are some differences between the need for publicity and the need for privacy based on studies in the behavioral economic field.
- Incomplete information about risks that leads decision makers to be optimistic in decision making.
- The solution inherent in protecting personal information
- Bounded cognitive abilities that limit our ability to consider or reflect on the consequences of privacy-relevant actions.
- Various systematic deviations from the abstractly rational decision process.

To avoid the influence of different factors that lead decisions to be an error, the processes of decision making were identified. One of them is *the canonical model (Tang, 2006)*. Processes in this model comprise of 7 steps

- Recognition that a problem or an opportunity exists
- Defining the problem or opportunity
- Specifying goals and objectives,
- Generating alternatives
- Analyzing alternatives
- Selecting an alternative
- Learning about the decision

This model is used to facilitate a structured approach to decision-making activities. Processes in this model are similar to SPALTEN as described in Section 2.1.4.Only some sub-activities are different such as specifying goals and objectives, and analysing alternatives. Specifying goals is a part of "S-Situation analysis" in SPALTEN. Analysing alternatives and selecting an alternative can be combined in L-the selection of solution in SPALTEN.

Within the activity of decision making, López and the team (López-Mesa & Bylund, 2011) identified 7 sub-activities including *specify*, *evaluate, validate, navigate, unify, decide, and others*.

- *Specify* is a statement concerning the compilation of design criteria.
- *Evaluate* in a statement concerns either the value of an alternative or the alternatives with respect to the current criteria.
- *Validate* is a statement about whether a design proposal is fit for the purpose with respect to identified product life concerns.
- *Navigate* is a statement regarding the progression and feasibility of the design work.
- *Unify* is a statement concerning the current solution in relation to the whole process.
- *Decide* is a verbally expressed decision long-time.
- *Other* is a statement that does not belong to any of the first six categories.

Processes of decision making and relevant components are explained in Figure 2.15, which shows a general model of decision-making (Bahl & Hunt, 1984). It shows decision making within an environment frame and dynamic.

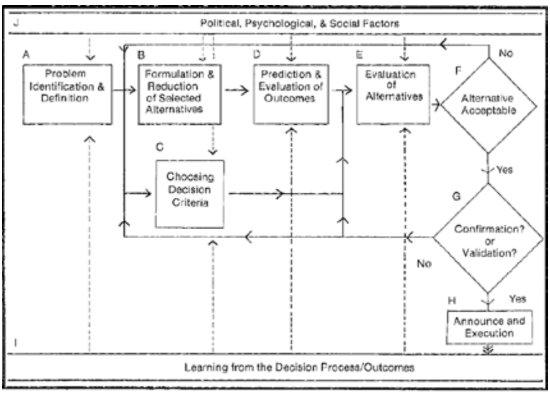


Figure 2.15**:** A general model of decision making (Bahl & Hunt, 1984)

2.3.4 Types of decisions (rational/heuristic) and decision model

From 2 thinking systems described by Kahneman in Section 2.3.2, decision making can be seen in terms of rational decision-making and intuitive decision-making.

Rational decision-making is usually described when decision making is striving for maximum utility. This decision requires complete information and is based on the knowledge of alternatives, knowledge of consequences, and decision rules (Kihlander, 2011a). It is one that conforms either to a set of general principles that govern preferences or to a set of rules that govern behavior (Stirling, 2003).

Intuitive decision-making is another system that is usually based on relatively simple, context-insensitive heuristics (Dane & Pratt, 2007; Tversky & Kahneman, 1974). Decision makers are guided by habits, instincts, and experiences when using intuitive decisions (Kihlander & Ritzén, 2012). They usually follow intuitive decisions when they are in time pressure (Kruglanski & Freund, 1983) and complex situations, which sometimes provide a better decision than using systematic decisions (Beresford & Sloper, 2008). A level of domain expertise affects the effectiveness of intuition.

A rational decision is not the same thing as making a good decision. If the outcome was desirable, the decision was a good one (Herrmann, 2015). Rational decisions can be classified into 4 types:

1) Substantive rationality: decision makers in substantive rationality will select the alternative that is optimal in the total preference ordering. They can define that one option is better than another. However, decision makers require a complete understanding of the situation and extensive computation effort.

2) Procedural rationality: decision makers with procedural rationality use knowledge about the behavior that is appropriate for given situations to determine the best course of action. The problem of the decision in this group is a rule may yield solutions with poor quality and no guarantee of optimality.

3) Bounded rationality: it is the best decision that could be done in the time available. This rationality starts with the observation that information and computational power are limited in the real-world. This prevents complete optimization.

4) Intrinsic rationality (Stirling, 2003): this type is described an idea of “you get what you pay for”, whether the expected benefits of the alternative exceed the expected loses. If the quality of alternative is lower than expected, that alternative will be rejected.

Ecological rationality is another group that determines when a given decision-making heuristic will be successful and when it will fail (Todd & Gigerenzer, 2007). It specifies the norms of rational action what should we do in order to act rationally. This group claims that the rationality of a decision relies on the circumstances in which it takes place. Therefore, the thing that is considered under the rational choice is not always be considered rational under ecological rationality.

There are 2 decision models that can be found in fast and slow thinking: a cognitive model and a context model (Dolan et al., 2012). The cognitive model is based on influencing what people consciously think about. Behavior can be influenced by changing minds. Another contrasting model is a context model, which focuses on the more automatic processes of judgment and influence. This focus leads away from facts and information, and towards the context within which people act. This model recognizes that people are sometimes irrational and inconsistent in their choices because of surrounding factors.

2.3.5 Decision evaluation

Evaluation of decision making can be identified from different perspectives, which related to types of decision theory.

In the *normative* type, the decision-making process can be controlled, but the result cannot be controlled. The outcome is not suitable to evaluate factors in decision quality.

Quality of decisions in the *descriptive* type can be measured by 3 measures (Nutt, 2003):

1) ***A measure of decision value***: this measurement focuses on the impact, merit, and satisfaction
2) ***A measure of development time***: this measurement relevant to decision cycle time and evaluation. Time pressure (a decision must be made by a certain point in time) has been shown to be one of the most important decision task variables. Errors in judgment can be made from either deciding too soon (rush-to-judgment) or from delaying decisions too long (Beresford & Sloper, 2008).
3) ***A measure of decision use***: this measurement includes initial adaptation, sustained adaptation, and full adaptation.

Prescriptive types define the quality of decision making based on 6 criteria: a committed decision maker, the right frame, the right alternatives, the right information, clear preferences, and the right decision procedures (Howard, 1992). Blenko

(Blenko et al., 2010) suggested 4 components to evaluate decision effectiveness using Quality (Q), Speed (S), Yield (Y) and Effort (E). The effectiveness can be calculated from Equation 2.1. Score for each question starts from 1 to 4. The meaning of each score is described in Table 2.4: Meaning of score for each component of decision effectiveness (modified from (Blenko et al., 2010)).

$$\text{Decision effectiveness} = Q*S*Y*(E/4) \qquad 2.1$$

Quality (Q): How often do you choose the right course of action?
Speed (S): How quickly do you make decisions compared with your competitors?
Yield (Y): How often do you execute decisions as intended?
Effort (E): Do you put the right amount of effort into making and executing decisions?

Table 2.4: Meaning of score for each component of decision effectiveness (modified from (Blenko et al., 2010))

Score	Description for each component			
	Quality	Speed	Yield	Effort
1	Never	Much slower than competitors	Never	We are off the charts
2	Infre-quently	Somewhat slower than competitors	Infrequently	We put in way too much/nowhere near enough effort
3	Some of the time	Somewhat faster than competitors	Some of the time	We put in somewhat too much/too little effort
4	Most of the time	Much faster than competitors	Most of the time	We put in exactly the right amount of effort

2.4 Heuristic decisions and biases

Kahneman (Kahneman & Tversky, 2013) describes heuristic as a cognitive shortcut or rule of thumb that simplifies decisions and represents a process of substituting a difficult question with an easier one. The heuristic can lead to cognitive biases and be a source of errors and a source of efficiencies. In the bounded rational model, the researchers in this group propose the heuristic as an important tool to support decision making. The heuristic is viewed as a simple strategy to make a decision by ignoring part of the information, with the goal of making decisions more quickly, frugally, and/or accurately than more complex methods (Gigerenzer & Gaissmaier, 2011). The heuristic requires less cognitive resources for its recruitment and execution and operated by exploiting concepts (Chow, 2014). Sometimes the heuristic can produce a good outcome but cannot guarantee a correct solution (Dunbar, 1998) and does not always work (Fodor, 2008). Heuristics that usually support decision making are defined as an adaptive heuristic. The examples in this group are Recognition heuristic, Take-the-best, Tallying, Satisficing, Imitate the majority, and Fast-and-Frugal-Trees (Gigerenzer & Brighton, 2009). People often make choices based on a single reason, such as prices or health in a shopping application. They use fast and frugal heuristics for decision making (Kalnikaitė, Bird & Rogers, 2013). The definition of each heuristic is described in Table 2.5

Table 2.5: Examples of adaptive heuristics that support decision making

Adaptive heuristic	Definition
Recognition heuristic	If one of two alternatives is recognized, infer that it has a higher value on the criterion.
Take-the-best	To infer which of two alternatives has the higher value, go through cues in order of validity until there is a cue that discriminates the two alternatives, then pick the alternative this cue favors.
Tallying	To estimate a criterion, do not estimate weights but simply count the number of positive cues.
Satisficing	Search through alternatives and choose the first one that exceeds your aspiration level.
Imitate the majority	Consider the majority of people in your peer group and imitate their behavior.
Fast-and-Frugal trees	Skimmed down the decision tree with each node connecting only to one further node and an exit.

Another research group defines heuristic as a decision bias. The heuristic is viewed as a mental shortcut for the fast processing of information, which can induce systematic error of judgment and create or influence gaps between planned intentions and realized actions (Samson, 2014). The heuristic can lead to memory errors, inaccurate judgments, and faulty logic (Evans, Barston & Pollard, 1983; West, Toplak & Stanovich, 2008).

2.4.1 Reliability and measurement of heuristic decision

A heuristic decision is usually effective when applying after careful consideration in an ecological rational environment that is adapted to the structure of the information on the environment in which they are used to make decisions. Using the heuristic to make a decision under uncertainty is better than using it under risk. Even if the people who have high experience are usually unconscious when using heuristic decisions, they can better recognize the appropriate environment and the appropriate timing for using a certain heuristic from their well-assorted heuristic toolbox. The efficiency of heuristic decision can be evaluated from different types of the test.

Competitive test: this test uses multiple models of strategies and determine which ones can predict the data the most accurately. Decision makers should not test only one model and state that the result appears to be good enough or not.

Individual-level-test: this is a test for each individual. Decision makers should not test what the average individual does because systematic individual differences can make the average meaningless.

Adaptive selection of heuristics: this is a test whether people use a heuristic in situations where it is ecologically rational. Heuristic decisions should not be tested whether everyone uses one heuristic to make a decision all the time of making the decision. Different situations can lead decision makers to use different types of heursitics to make decisions.

2.4.2 Types of cognitive biases

A heuristic decision is sometimes seen as an irrational decision. However, it may be possible to determine which type of rationality it appears to fit (Todd & Gigerenzer, 2007). Biases can be classified into 2 types: cognitive bias and motivation bias using decision and risk analysis (Arkes, 1991; Montibeller & Winterfeldt, 2015). Cognitive bias is a systematic discrepancy between the correct answer in a judgment task and the decision maker. Motivation bias happens when judgments are influenced by the desirability or undesirability of events, consequences, outcomes, or choices. These biases can lead decisions to be errors. Types of error, classified by psychological field, consist of Strategy Based (SB) error, Association Based (AB) error, and Psychophysically Based (PB) error. SB error occurs when decision makers use a suboptimal cognitive strategy. AB error is a consequence of automatic mental associations. PB error results from incorrect mapping between physical stimuli and psychophysical responses.

One source of decision biases and errors is the heuristic. Different types of heuristic generate different types of bias and error. Kahneman (Kahneman, 2011) proposed 3 fundamental heuristics, which are representativeness, availability, and anchoring.

2.4.2.1 Representativeness

The representativeness heuristic is usually used when making judgments about the probability of an event under uncertainty. People usually rely on the representativeness heuristic, in which probabilities are evaluated by the degree to which A is representative of B or the degree to which A resembles B (Tversky & Kahneman, 1974). When A is representative of B, the probability that A originates from B is judged to be high. On the other hand, the probability that A originates from B is judged to be low when A is not similar to B. Decision makers use additional information to make a decision even when sound recognition was established(Dietrich, 2010). Representativeness can lead to mental mistakes by judging probabilities and risks based on the category of this object, person, or process presents (Virine, Trumper & Virine, 2018). For example, participants consider the information about Steve and assess the probability that this person is engaged in a particular occupation from a list of possibilities (farmer, salesman, airline pilot, librarian, or physician). Steve is very shy and withdrawn, invariably helpful, but with little interest in people, or in the world of reality. He has a meek and tidy soul. He also has a need for order and structure, and a passion for detail. Results showed that participants order occupations by probability and by similarity in the same way. People assess the probability that Steve is a librarian from the degree to which he is representative of, or similar to the stereotype of a librarian. However, this approach to the judgment of probability can lead to serious errors, because similarity or representativeness is not influenced by several factors that should affect judgments of probability (Tversky & Kahneman, 1974).

2.4.2.2 Availability

Availability is a heuristic of judgment that substitutes one question for another. People make judgments about the probability of certain events based on how easy it is brought to their mind (Virine et al., 2018), and the received information that is most readily available in making a decision (Redelmeier, 2005). The similar process of this heuristic is salience, whereby information that stands out is novel or seems relevant and is more likely to affect our thinking and actions (Dolan, Hallsworth, Halpern, King & Vlaev, 2010). Even the availability heuristic seems to produce decision bias and error. This heuristic can be used to achieve behavior changes in a positive way. The example can be seen in the research by Ukpong (Ukpong, N., Saini, P., & Al Mahmud, A., 2011). He showed that children's ability to identify more energy-efficient behaviors, increases by the use of educational interactive systems. Children will get a positive influence by playing a game that is designed to present more energy-efficient behavior. In the other word, children use availability heuristic to increase their education.

This heuristic is also applied to predict the level of product risk. Product failures can be estimated by determining how easy it is to bring such events to mind (Folkes, 1988). Significant changes in consumers' behaviors occur when they perceive a risk of purchasing a product (Andersson & Johansson, 2014).

2.4.2.3 Anchoring and adjustment

Anchoring heuristic usually involves numeric judgment under uncertainty (Esch, Schmitt, Redler & Langner, 2009). It is the foundation decision-making heuristic in situations where some estimated value is needed (Epley & Gilovich, 2006). People make an estimation by starting from an initial value that is adjusted to yield the final answer. However, adjustments are sometimes insufficient. The anchoring heuristic can also involve an image or other stimuli that is not numeric (Esch et al., 2009). Decision makers are commonly relied on anchors or a particular piece of information or reference point to make decisions. These anchors or initial points may be suggested by the formulation problem, or it may be the result of a partial computation. Therefore, different initial points yield different estimates (Tversky & Kahneman, 1974). If this anchor is set up incorrectly or inappropriately, decisions can be wrong (Virine et al., 2018).

Two groups of high school students are in a study of this bias. They are assigned to estimate a numerical expression that was written on the blackboard within 5 seconds. The first group estimated the product 8x7x6x5x4x3x2x1, while the second group estimated the product 1x2x3x4x5x6xx7x8. Based on a short time calculation, they have a few steps for computation and then estimate the product by estimation and adjustment. The average in the first group is 2,250 and the second group is 512. The correct answer is 40,320. The different average numbers between 2 groups come from the different results of the first few steps of multiplication. The first few steps of multiplication in the first group are higher than the first few steps of multiplication in the second group. Therefore, the former expression in the first group is judged larger than the second group. This is an example of bias in the evaluation of conjunctive and disjunctive (Tversky & Kahneman, 1974).

After these three heuristics are presented, other decision biases are then proposed, described and studied from many researchers. These examples of heuristic decisions and biases are shown below.

Social bias

Decision makers who have a social bias will choose what the majority of one's peers are choosing, such as thinking of getting married when most others in one's social group do (Esch et al., 2009). They make a decision based on other people instead of using their own information or making independent decisions (Banerjee, 1992). This behavior can be seen in the domain of finance, where it has been discussed in relation to the collective irrationality of investors, including stock market bubbles.

Losses and gains

This bias is a fundamental resource of the framing bias. The difference between 2 options will be viewed as greater if framed as a difference between disadvantages and advantages or losses and gains with respect to the reference point (Beresford & Sloper, 2008).

Decoy effect

This heuristic usually happens in solution selection from the choices. Decision makers select the solution regarding an offering from choices rather than based on absolute preferences. It is technically known as an asymmetrically dominated choice and occurs when people's preference for one option over another changes as a result of adding a third option that is similar but less attractive (Samson, 2014).

Status-quo bias

Status-quo bias is a bias that tries to maintain the current situation and not change behavior unless the incentive to do so is strong (Samson, 2014). Decision makers prefer to do nothing or stick with the decision that is made previously (Samuelson & Zeckhauser, 1988). This bias is consistent with loss aversion. They try to avoid regret from changing a decision. A study from Kahneman and Tversky (Kahneman & Tversky, 1982) shows that people feel greater regret for bad outcomes that result from new actions taken than for bad consequences that are the consequences of inaction (Samson, 2014). A higher level of influence of the status-quo bias relies on the more level of decision makers' experience (Burmeister & Schade, 2007). The research from Burmeister and Schade shows that entrepreneurs are affected more by the status quo as a student but less affected than bankers. The experience of investment in bankers is higher than entrepreneurs and students.

Endowment effect

Decision makers who have this bias tend to rely on what they have chosen before and what represents the current state, or even what someone else has chosen for them consequently (Burmeister & Schade, 2007). They assume that their tastes or preferences will remain the same over time. Differences between the present and future valuations are particularly underappreciated for durable goods, where satisfaction levels fluctuate over time (Samson, 2014). This effect can be seen as „willingness-to-pay (WTP) for a good that is systematically lower than a willingness-to-accept (WTA) for the same good possessed by an individual (called WTP-WTA disparity) (Tversky & Kahneman, 1991). Status-quo bias, endowment effect, and WTP-WTA disparity are consistent with reference dependence together with loss aversion according to prospect theory (Kahneman & Tversky, 1979; Tversky & Kahneman, 1991).

Sunk-cost bias

This bias occurs when mistakes are perpetuated from the past. Decision makers try to continue behavior as a result of previously invested resources such as time, money or effort (Arkes & Blumer, 1985). This bias is similar to status-quo bias and can be viewed as bias resulting from an ongoing commitment (Samson, 2014). In product development, gatekeepers sometimes escalate a commitment to the front end of new product development before substantial investments in new product development projects have been made (Sleesman, Conlon, McNamara & Miles, 2012).

IKEA effect

The IKEA effect is a cognitive bias that the ownership of a product increases its value to individuals (Norton, Mochon & Ariely, 2012). Consumers place a disproportionately high value on products they partially created. This effect gives the shift from mass production to increase customization and co-production of value. Decision makers have positive feelings that come with the successful completion of a task, a focus on the product's positive attributes, and the relationship between effort and liking (Kruger, Wirtz, van Boven & Altermatt, 2004). This name comes from the name of Swedish manufacturer furniture retailer IKEA, which sells many furniture products that require assembly.

Confirmation bias

Decision makers try to seek out information that supports an existing belief and expectations and discounting opposing information (Hernandez & Preston, 2013). This bias is related to primary effects and anchoring (Nickerson, 1998). Bias can increase the risk to overestimate the probabilities of unlikely events in decisions when all evidence is not considered fully. Kahneman (Kahneman, 2011) shows that confirmation bias can be caused by associative memory when asking someone who is friendly or unfriendly. Different instances of the person's behavior will come to mind to the participant depending on how the question is addressed and lead the answer to be different even though the question is the same (Andersson & Johansson, 2014). This behavior comes from the rising of the associative memory in System 1 that is triggered by specific descriptions.

Overconfidence bias

This bias can be observed when decision makers are confident in their own ability that is greater than their objective (actual) performance. This bias is similar to optimism bias when confidence judgments are made relative to other people. The planning fallacy is another example of overconfidence that people underestimate the length of time to complete a task and ignore past experience (Buehler, Griffin & Ross, 1994). Entrepreneurs usually encounter this bias; they try to enter a market despite the low chances of success (Moore & Healy, 2008) and might persist on the same decision even when new negative information becomes available (Eliëns et al., 2018).

Optimistic bias

Decision makers overestimate the probability of positive events and underestimate the probability of negative events. Optimistic bias comes from 4 factors: their desired end state, their cognitive mechanisms, the information they have about themselves versus others, and overall mood (Shepperd, Carroll, Grace & Terry, 2002). A possible cognitive factor that has been identified in this bias is the representativeness heuristic.

Hindsight bias

Hindsight bias comes from a part of the availability and representativeness heuristics, which also known as “knew-it-all-along effect”. This bias happens when being given information changes our recollection from an original thought to something different (Mazzoni & Vannucci, 2007). This bias causes us to believe that the causes of past events were simpler than they were. It can lead to distorted judgments about the probability of an event’s occurrence because the outcome of an event is assumed to be predictable.

The level of decision bias can be influenced by different environments such as the roles of decision makers and structures of alternatives. The example is decision making between managers and entrepreneurs. Entrepreneurs seem to use heuristic more than managers because managers access historical trends, and past performances, which makes for more rational ideals in their decisions (Busenitz & Barney, 1997). Entrepreneurs also encounter complex situations like managers.

Two types of heuristics that can be found with entrepreneurs and managers are overconfidence and representativeness. Managers in large companies have a low chance to rely on their personal confidence in making decisions. They can rely on decision making tools and historical performance patterns. Therefore, managers have a low chance to be overconfident rather than entrepreneurs. Representativeness usually appears in decision making when decision makers base decisions on information from a statistic. The position of alternatives can also lead to biased decisions.

One example is provided by Muthulingam (Muthulingam, Corbett, Benartzi & Oppenheim, 2013) in the project selection experiment. The project is selected more often when that project appears early in a list of projects. The item that is at the top of the list will be selected more often than the item that is at the bottom (Schiffels, Fliedner & Kolisch, 2018).

2.4.3 Decision biases in product development

Some examples of biases in product development and management were illustrated in the previous section with a specific type of biases. This section, however, shows possibilities of biases that can be appear in specific situations and activities.

In management, over optimistic and risk aversion are the most significant sources of error in strategic decisions (Lovallo & Sibony, 2006). Over optimistic plans and forecasts can lead the project to be delayed (Stingl & Geraldi, 2017), which is a result of the planning fallacy. Sunk cost effect and optimistic bias can lead to the Escalation of Commitment (EoC) situations in which projects are continued even when objective criteria like significant cost overruns and extreme delays show project failure.

In process of design and consumers, many cognitive biases can also appear during the process. Examples of these biases are optimism bias, hindsight bias, placebo effect, impact bias, loss aversion, status-quo bias, clustering illusion, planning fallacy, framing effect, endowment effect, anchoring, and the bandwagon effect (Girling, 2012). When generating alternatives and objectives, cognitive biases may appear as omission bias, anchoring and availability objectives (Montibeller & Winterfeldt, 2015). The omission bias can cause the failure to include important alternatives that turn out to be contenders or winners in an evaluation.

Cognitive biases when defining attributes such as criteria and performance measures are scaling bias, gain-loss bias, and proxy bias (Montibeller & Winterfeldt, 2015). Scaling bias is a family of biases, which occur when stimulus and response scales are mismatched. These biases are contraction bias (underestimating large sizes/differences and overestimating small/size differences), logarithmic response bias (using step-changes in the number of digits used in the response, which fit a log scale), range equalizing bias (using most of the range of response whatever the size of the range of the stimuli), centering bias (producing a systematic distribution of responses centered on the midpoint of the range of stimuli), and equal frequency bias (using equally all parts of the response scale). Gain-loss bias occurs when an attribute has a positive or negative connotation. Proxy bias influences a distortion in weights in multi-attribute utility models. When eliciting value and utility functions, anchoring bias and gain-loss bias can appear in decision making. When eliciting attribute weights, cognitive biases such as splitting bias, equalizing bias, proxy bias, range insensitivity bias, and desirability bias. Splitting bias is a bias when more details receive a larger portion of the weight than objectives that are defined in less detail.

In concept decision (Kihlander, I., & Ritzén, S., 2009), some companies made a concept decision by working on one track in the concept development based on the solution used in earlier projects. The solution gets too detailed too early forcing the team to focus on getting the solution to work instead of having discussions on a more conceptual level. Some decision makers use their personal experience to influence the concept of development in certain directions. Decision makers are convinced due to bad experience in a previous project to not use a certain solution.

Another Scenario is a design method used to predict a possible set of future conditions. In scenario planning, availability bias appears when making a decision by relying on ready information or evaluating trends only within the same geography or industry context. Another bias in the scenario method is the probability neglect that leads decision makers to focus on numerical precision early in the process. Decision makers also outsource and delegate the creation of scenarios to young team members, which is a stability bias when creating scenarios. Optimistic bias and overconfidence bias happen in planning for a scenario deemed to exclude all others. Decision makers should access the impact of each scenario and develop strategic alternatives for each. The last bias is a social bias using scenario planning as a one-off exercise or ignoring social dynamics such as groupthink (Erdmann, Sichel & Yeung, 2015).

2.4.4 Heuristic decision in alternative evaluation

Human action is usually viewed as the result of human choice that also views decision making as intentional (March, 1991). Four factors that can impact human action are defined in the following.

1) The knowledge of alternatives: decision makers have a set of alternatives for action.
2) A knowledge of consequences: decision makers know the consequences of alternative actions.

3) A consistent preference ordering: decision makers have consistent values by which alternative consequences of an action can be compared.
4) A decision rule: decision makers have rules by which they select a single alternative of action on the basis of its consequences for the preferences.

Choices are usually analyzed in a rational way (Green, 2002). Decision makers identify the relevant factors and make assumptions about their objectives. They also identify the constraints faced by each factor. Then decision rules of each factor are determined, which describe how one factor responds to changes of one kind or another. Mathematics is usually applied to the constraint optimization problem in this task, but it is sometimes quite sophisticated when determining the decision rules of various factors. Decision makers will explore the balance of the model changes in response to various external events and examine whether the predictions in the previous steps are consistent with the actual experience. This step requires the statistical analysis of data and can involve cultivated techniques such as controlling sample selection bias. In the end, all conclusions and implications are summarized. However, information and computation are limited on human choice in terms of the number of considered alternatives, the amount of available information, and influences of actions and experiences to concurrent preferences (March, 1991). Therefore, a decision is not usually made by systematic decision but is instead made by heuristic decision. Then cognitive biases can happen in choice selection starting from when generating alternatives and objectives, defining attributes, eliciting value and utility functions, and eliciting attribute weights (Montibeller & Winterfeldt, 2015). Table 2.6 shows biases in each sub-activity in Multi-Criteria Decision Analysis (MCDA).

Table 2.6: Decision biases in Multi-Criteria Decision Analysis (MCDA) (Montibeller & Winterfeldt, 2015)

Activities in MCDA	Biases	Description
Generating alternatives and objectives	Omission bias	Important items are omitted, which leads to the failure to include important alternatives that may turn out to be contenders or winners in evaluation
	Anchoring	Alternatives are anchored on an initial set
	Availability	The existence of one alternative prevented the generation of other ones
	Desirability bias	The exclusion of alternatives that compete with the preferred one
Defining attributes	Scaling bias	Presenting and scaling an attribute in different ways such as the definition of upper and lower limits of the attribute scale
	Contraction bias	Overestimate or underestimate the size of attributes
	Logarithmic response bias	Use log scale in step-changes in the number of digitals used in the response
	Gain-loss bias	An attribute has a positive and negative connotation
Eliciting value and utility functions	Anchoring bias and gain-loss bias	Define value from the initial value and based on a positive and negative perspective
	Certainty effect	Prefer sure things to gambles and discount the utility of sure things.
	Desirability bias	Distort the utility function by favoring a preferred alternative
When eliciting attribute weights	Splitting bias	Provide a larger portion of the weight to the object that is defined in more detail than the objective that is defined in less detail.
	Equalizing bias	Allocate similar weights to all objectives
	Proxy bias	Using proxy attribute instead of an attribute that directly measures a fundamental objective can lead objectives to be overweight

The quality of a decision can also be influenced by the number of alternatives. Decision makers have low efficiency to process information with many alternatives when compared with two or three alternatives (Beresford & Sloper, 2008). Schwartz (Schwartz, 2004) claimed that more information and more choices are not always better. Over choice can lead decision makers to be unhappy and reduce self-control due to decision fatigue (Vohs et al., 2014). They then will go to the default option, as well as choice deferral by avoiding making a decision altogether (Iyengar & Lepper, 2000). Experts usually base their decisions on a few pieces of information (Shanteau, 1992). A chance that customers will buy a product when encountering a few pieces of information is also higher than encountering a lot of information (Iyengar & Lepper, 2000). People will stop searching for a cause when they have a good hypothesis in mind. This hypothesis then blocks their ability to see alternatives. When one option is chosen, they will then experience a loss, and the rejected option will be more valuable. This situation leads decision makers to regret the decision they made (Carmon, Wertenbroch & Zeelenberg, 2003). One way to reduce decision bias is to choose the number of alternatives by using smaller sets of attributes and highlighting only the most important attributes from each small set (Johnson et al., 2012).

Another bias when analyzing alternatives is to assign equal probabilities to each event that occurs and equal importance weights to each attribute that is explicitly identified (Fox & Rottenstreich, 2003; Fox & Clemen, 2005). These weights manage preferences by assigning a favored option to separate the superordinate category and a disfavored option to a single superordinate category creating increased chance for selecting the favored option. This is the way to design alternatives to control decision behavior using the decoy effect (Johnson et al., 2012). The individual feeling that attaches to different choice options and the role of past experience can influence information processing and the way in which options are viewed. It is important to lead decision makers to focus more on information and minimize emotion (Beresford & Sloper, 2008).

Choice architecture is one concept idea to design decision environments encountered by decision-makers and to support or control decision maker's decisions (Johnson et al., 2012). Richer Thaler and Cass Sunstein propose a method to design environments or choice architecture to influence decisions using "nudge strategy" (Thaler & Sunstein, 1945) as a default.

Other components will be described in detail in the next section. Default, framing or adding decoy options can influence choice by changing the manner in which options are presented to people (Samson, 2014). The way information or attributes of options is presented will affect the decision made such as presenting advantages/disadvantages and losses/gains with respect to a reference point (Beresford & Sloper, 2008). The framing effect is quite similar to the prospect theory (Kahneman & Tversky, 1979) that framed choices in a way that highlights the positive or negative aspects of the same decision. Types of framing can be classified into 3 types: risky choice framing (proposing to lose and gain), attribute framing (proposing good and bad), and goal framing (proposing reward and penalty) (Samson, 2014).

In conclusion, five essential points for the solution selection from multiple choice are described as the following (Johnson et al., 2012).

1) A number of alternatives: around 4-5 non-dominating options can present reasonable initial value for choice architecture.
2) Technology and decision aid: the decision tools should assist choice tasks and provide a recommendation.
3) Default: the preferred alternative is set as a recommendation.
4) Choice over time: Drawing attention to the delayed options can refocus the decision maker to generate more patient choices.
5) Minimizing the experiences of negative emotion during making the decision and afterward, maximizing the ease of justification of a decision to oneself and to others.

2.5 Potential techniques to control decision making

2.5.1 Key elements to improve decision making

A decision is an important activity in our daily life. Skill to make a good decision is then required to make a better decision and success in the future. KIHLANDER (Kihlander, 2011b) proposed 5 key elements to improve a concept of decision making. These key elements are:

1) Create meta-knowledge and awareness regarding what influences the process and the actors in the process
2) Ask questions to ensure that aspects previously neglected are considered
3) Provide visualization to enhance understanding of both process and solutions
4) Provide vision as guidance to help everyday decision making and trade-offs
5) Ensure reflections since there is a need for actors in the process to reflect on their own decision-making process

Moreover, a decision maker should be aware of the decision process, be able to follow decision rules that relate to gate criteria, and be in control of one's own emotions (Eliëns et al., 2018). To make an effective decision, a decision maker has to work on the right decision problem. Then the objectives should be specified by considering the interests, values, concerns, fears, and inspirations in relation to the goal. After that, the decision maker should create imaginative alternatives and understand the consequences of alternatives in a proper way. A method to intelligently select a solution is to choose from less than perfect alternatives when comparing competing objectives. Moreover, a decision maker should clarify the uncertainties and think hard about risk tolerance. In the end, a decision maker should consider linked decisions by isolating and resolving near-term issues while gathering information needed to resolve issues that will arise later. Eriksson (Eriksson, 2009) defined 6 components that will support the effectiveness of decision making, which are

- A committed decision-maker
- The right frame
- The right alternatives
- The right information
- Clear preferences
- The right decision procedures.

Decision making can also be seen in terms of selecting a solution from alternatives. Therefore, considering alternatives is an essential step in decision making. This step requires 6 activities of decision making (López-Mesa & Bylund, 2011).

1) *Tentatively deciding (TD):* the decision is based on available information. A decision maker will decide whether to go or not for solution 2.
2) *Uttering tentative biased knowledge (TK):* knowledge in this step is used to support the tentative decision of rejecting solution 2.
3) *Posing decision-oriented questions (PQ):* a decision maker tries to go from a tentative decision to a final decision by investigating a number of answer maps that can be introduced in solution 2.
4) *Validating knowledge or accessing already validated knowledge (VK):* all answers that can be mapped to solution 2 should be validated.
5) *Biasing solving (BS):* an already proposed solution is refined in order to influence a pending decision. For example, team is convinced that solution1 is better than solution 2.
6) *Validating decisions (VD):* a decision maker decides whether or not to reject an idea, or whether an idea is better than another.

2.5.2 Improve decision making in the organization

As described in the previous section of the literature review on decision making in product development and management, decision making is sometimes erroneous providing mistakes. It is necessary to improve and practice decision making. Kihlander (Kihlander, 2011b) developed a model to improve concept decision making as showing in Figure 2.16.

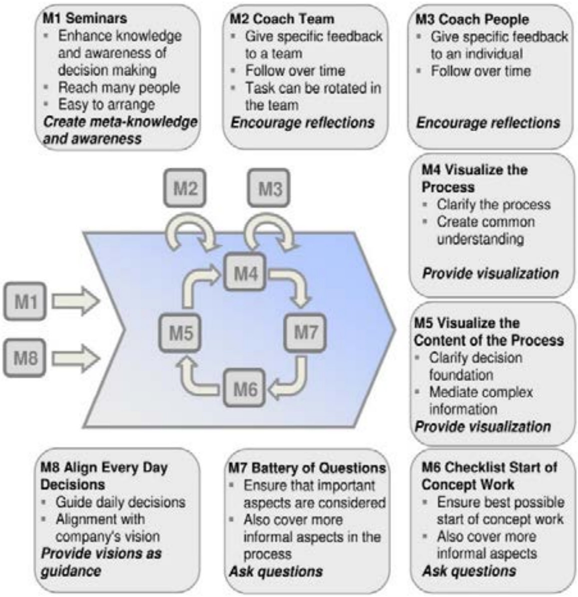


Figure 2.16: A model to improve concept decision making (Kihlander, 2011b)

Creating meta-knowledge and awareness by seminars is the first component to improve decision making in an organization. The organization then should encourage reflections by coaching teams and employees during the project. The process and contents of the procedures are presented to all members to enable a common understanding.

Use of a checklist to assist asking appropriate questions is a good process to ensure important aspects are covered and to check the quality of work.

The last important component is to provide visions as guidance in everyday decisions. An organization should guide daily decisions to be aligned with the company's vision. These steps can help the organization to make a better decision.

An idea to improve decision making in judicial decisions is another interesting method that can be applied in the organization. When judges make repeated rulings, the tendency to rule in favor of the status quo increases. Therefore, taking a break to eat a meal for example, is one way to overcome this bias. This method is consistent with the previous research that demonstrates the effects of a short rest, positive mood, and glucose on mental resource replenishment (Danziger, Levav & Avnaim-Pesso, 2011).

There are many cognitive biases in the organization that are similar to the example of the status quo. In management (Andersson & Johansson, 2014), individuals usually tend to stick with their original opinion based on prestige. This bias can be reduced by listing pros and cons of different solutions, deducing the best resolve.

Self-interest is another bias that can be seen from managers. Arranging a senior-management seminar, where participants need to propose individual preferred strategies, is one way to help individuals widen their perspectives. This experience opens their eyes to alternative methods and ideals, expanding the probability of their success. Bias in the meeting can also be a benefit by using the debate to break down weak arguments, creating a learning environment with feedback systems to compare outcomes to forecasts and expectations.

Methods to repair cognitive bias can be classified into 2 groups, which are motivation repairs and cognitive repairs (Heath, C., Larrick, R. P., & Klayman, J, 1998). Motivation repairs are the methods to increase the energy and enthusiasm with which individuals pursue a task. Cognitive repairs are the methods to improve the mental procedures of individual users to decide which task to pursue and how to pursue it. These repairs usually focus on raising the decision maker's awareness by increasing procedures of decision making and adding reminders. However, these repairs should be trained to avoid cognitive bias. Table 2.7 shows some cognitive biases and methods to repair each bias in an organization (Heath, C., Larrick, R. P., & Klayman, J, 1998).

Table 2.7: Examples of cognitive biases and repair methods (Heath, C., Larrick, R. P., & Klayman, J, 1998)

Cognitive bias	**Repair methods**
1. Individual focus on people rather than the situation	Reminding individuals to consider causes other than people who are likely to be closest to any problem
2. Individuals stop searching as soon as they generate one hypothesis (When people have one good hypothesis in mind, that hypothesis often blocks their ability to see alternatives)	One technique is "Five Whys"-> ask why? Five times before generating a hypothesis which helps people to find a root cause rather than a superficial one "why?" is used to invoke some salient and cause individuals to think more broadly and situation-ally

Cognitive bias	Repair methods
3. Individual generates hypotheses that are narrow rather than broad. Therefore, alternatives often differ only slightly from one another and all lie within the same general frame	Individuals might search more broadly if they are cued to think about a problem from different perspectives "be dragonflies (compound eyes) but not flatfish (big eyes but only in one direction)" Encouraging individuals to recruit others who have different perspectives
4. Individuals often collect small samples of information. They typically believe that small samples will be quite similar to the population from which they are drawn "law of small number"	Encouraging or requiring individuals to collect larger samples. This kind of repair is pervasive in writing on TQM (total quality management) "provides individuals with tools that help them collect and analyze data
5. Individuals draw conclusions that underestimate the amount of uncertainty and error in their predictions, but they tend to do it asymmetrically-they rarely overestimate a project's cost or time to completion	Allow an individual to make overconfident predictions, then adjust them overtly (safety factor)

Each activity in the repair methods from Table 2.7 are nearly similar to activities in SPALTEN that aims to support problem-solving situation. For example, considering causes of problem in the first raw has the same idea as P: problem containment in SPALTEN.

The cognitive repairs are classified into 6 different dimensions.

1) ***Simple vs Complex***: simple repairs have advantages over complex repairs.
2) ***Domain-specific vs Domain-general***: domain-specific is easier to recognize and apply than domain-general
3) ***Corrective vs Preventative***: corrective repair only interferes at the end of a process to correct the overall outcome. On the other hand, preventive interferes early in a cognitive process before drawbacks have had a chance to perform.
4) ***Familiar vs Novel***: familiar repairs can provide advantages over novel repairs because less effort is used.
5) ***Social vs Individual*****:** social repairs are usually used because of individual intention. Individuals do not usually recognize the need to repair themselves.
6) ***Top-down vs Bottom-up***: top-down is designed by managers or outside experts. On the other hand, bottom-up requires informal observation or discovery from the people who are doing the work, which is simpler and more domain-specific than top-down repairs.

Within the methods to support decision making, cognitive biases also appear as described in Section 2.4. Montibeller and Winterfeldt (Montibeller & Winterfeldt, 2015) described cognitive repairs in each step of Multi-Criteria Decision Analysis (MCDA). When generating alternatives and objectives, one objective is presented at a time and asking respondents to generate alternatives that meet this objective. More alternatives should be generated when no objectives or all objectives together are presented.

When defining an attribute, natural units such as centimetre (cm) should be used. A positive and negative frame in assessing performance should also be considered. Standardized shapes should be applied for utility functions such as linear value function when eliciting value and utility function. Shared mental models by group members can increase the effectiveness in reaching a decision and satisfaction with the decision-making process.

The last activity is eliciting attribute weights. Respondents should avoid excessive detail in some objectives and provide more detail in others to prevent splitting bias. The lower and upper anchors of each attribute can be set up by using a ranking method to avoid equalizing bias.

2.5.3 Methods to improve the decision and cognitive biases

Improving decision biases can be understood in terms of the de-biasing technique. It is a technique, which attempts to eliminate or reduce cognitive or motivational biases (Montibeller & Winterfeldt, 2015). Different biases require different levels of de-biasing techniques. Some biases are difficult to be corrected and tend to be resistant to logic, decomposition, or the use of training and tools. Examples of biases in this group are the overconfidence bias, anchoring and insufficient adjustment, and the equalizing bias. Another group of biases can use logic and decomposition to eliminate biases. Biases in this group are including conjunction fallacy and neglect of base rates.

Many methods are proposed to de-bias different biases. The following information will described de-biasing methods based on types of biases.

- *Anchoring bias*: this bias can be reduced by using more than one reference point during an analysis of an issue (Virine et al., 2018). Another way is activating system 2 by searching the memory for arguments against the anchor (Galinsky & Mussweiler, 2001). “Thinking the opposite” is a strategy against these effects (Kahneman, 2011). However, it is not easy to reduce or eliminate the anchoring effect because system 2 usually works on data retrieved from memory, where an anchor makes it easier to retrieve certain data (Andersson & Johansson, 2014). Prompting the subjects to consider reasons instead of the anchor is another way to alleviate the bias (Montibeller, G., & von Winterfeldt, D., 2015).

- *Availability bias*: collecting as many samples of reliable information and combining it with analysis, is one method of avoiding availability bias (Virine et al., 2018). This bias can also be resisted when reconsidering your feelings and decisions (Kahneman, 2011). Mahanani (Mohanani, Salman, Turhan, Rodriguez & Ralph, 2018) proposed 3 steps to avoid availability bias, which are

1) Developing a frequently asked questions document
2) Introducing spelling conventions
3) Using ontology-based documentation formalize multiple relationships between discrete pieces of scattered information by facilitating a traversal search.

- *Representativeness bias*: a de-biasing technique for this bias is to think about different methods of categorizing objects or events such as developing a software user interface. Using different methods such as user interface development, suitable tools, and decision-making capabilities, in the same task can assist to avoid an influence of representativeness (Virine et al., 2018).

- *Self-serving bias:* decision makers in this bias usually search for an explanation that makes themselves look good. A method to avoid this behavior is to consider the base rate of success in the market or society.

- *Confirmation bias*: this bias can be avoided by changing the style of an argument presentation and bring out more opposing perspectives. Presenting the arguments in a disfluent format can lead decision makers to carefully analyze a process and increase effort to comprehend the material.

Other methods are proposed without specifying types of bias, which are:

1) Acquiring resources to improve decision bias (Campbell, Whitehead & Finkelstein, 2009) by:

- Injecting fresh experience or analysis: decision makers should explore new information from different people and different problems
- Introducing further debate and challenge by considering the opposite reaction: this method requires a balance in the group debating the issue. Examples of biases that are suitable for using

this technique are overconfidence, hindsight bias, and anchoring (Larrick, 2004; Mussweiler, Strack & Pfeiffer, 2000).

- Imposing stronger government: the requirement, that a decision is confirmed at a high level, provides a final safeguard.

2) Raising decision awareness (Kihlander & Ritzén, 2012): raising decision awareness of where traps of biases are likely to appear and trying to minimize the negative impact is a better approach than trying to avoid psychological traps.

3) Trying to remove oneself mentally from a specific situation or to consider the class of decisions to which the current problem belongs (Milkman, Chugh & Bazerman, 2009).

4) Making decisions in a group rather than as an individual will train individuals in statistical reasoning and make people accountable for their decisions (Larrick, 2004).

5) Applying an influence of framing effect: decision makers can use cognitive mapping to draw a diagram of casual relationships between relevant variables, which are presented as nodes (Hodgkinson, Bown, Maule, Glaister & Pearman, 1999).

Even an individual might feel a sense of confidence in a choice given a particular frame. This does not ensure that the same individual would make the same decision in another (Kahneman & Tversky, 2013). Therefore, seeking out different frames of the same problem is a suitable method to test the robustness of the initially preferred decision (Andersson & Johansson, 2014).

2.5.4 Potential methods to influence decision behavior

Brest and Milkman (Brest, 2013; Milkman et al., 2009) proposed essentially 2 ways to address biases originating in system 1, which are de-biasing and counter-biasing. De-biasing involves complex strategies for active System2 that is rationality and analytical processing. This technique has been described in the previous section.

Counter-biasing is, on the other hand, playing on the system 1 bias against another as in the classical simple “nudges” proposed by Thaler and Sunstein (Thaler & Sunstein, 1945). Examples are default option leveraging status quo bias or incentives framed as losses to leverage loss aversion.

Nudging is a method of structuring choice and sometimes helps people to learn to make a better choice on their own. It is voluntary, avoidable, easy or passive and low cost. It promotes the better choice as seen by the person being nudged as well as supporting decision makers' long term goals. Thaler and Sunstein (Thaler & Sunstein, 1945) defined nudging as any aspect of the choice architecture that alters people's behavior in a predictable way without forbidding any options or significantly changing their economic incentives. The intervention will be counted as a nudge when it is easy and cheap to avoid. A nudge is called for because of flaws in individual decision-making and works by making use of those flaws (Hausman & Welch, 2010). A nudge can influence people's judgment, choice or behavior by making use of cognitive boundaries, biases, routines, and habits in individual and social decision-making posing barriers for people to perform rationally in their own self-declared interests (Hansen, 2016). In an organization and management, a nudge is used to design organization contexts to optimize the fast thinking and unconscious behavior of employees in line with the objectives of the organization (Ebert & Freibichler, 2017).

Components for nudging proposed by Thaler and Sunstein (Thaler & Sunstein, 1945) are incentive (N), understand mapping (U), defaults (D), give feedback (G), expect error (E), and structure complex choices (S). These components are formed as an abbreviation that is “NUDGES”.

- *Incentive* motivates consumers to think hard and accurately by asking who uses, who chooses, who pays and who profits. The consumer has to believe that it is in his or her best interests to answer accurately (Hauser, 2014). The incentive can be used to increase labor productivity in the real marketplace (Hossain & List, 2012). There is a piece of evidence that framing can be used to enhance around 1% of productivity. However, it is more robust for groups than for individuals. Pecuniary incentives enhance productivity for both teams and individuals even when the incentives were provided unconditionally.

Figure 2.17: An example of Incentive from NUDGES (Thaler & Sunstein, 1945)

- *Understand mappings* is a technique to transform numerical information into units that translate more readily into actual use. An example is comparing a picture's quality in inch to be better than a pixel.

Figure 2.18: An example of Understand mappings from NUDGES (Thaler & Sunstein, 1945)

- *Default* is proper to de-bias status-quo bias. The default choice is designed for people who do not want to make an active choice. Inertia, procrastination, and lack of self-control are problems that make changes in default options from opt-in to opt-out as an effective strategy (Samson, 2014). One example is shown in Figure 2.19, which is applied in blood donation situation.

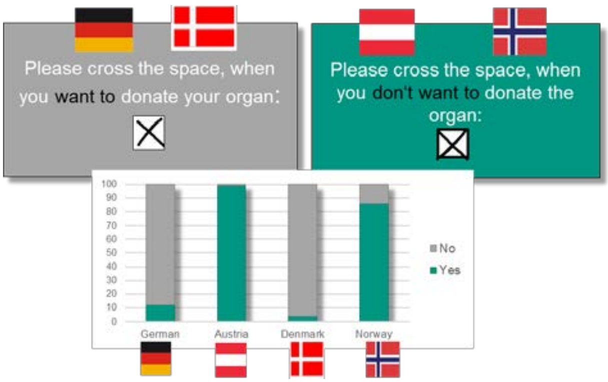


Figure 2.19: An example of default from NUDGES in blood donation situation (Samson, 2014)

The default option is usually used in a market by setting a well-designed product or service as a default option, which simplifies decision making, enhances customer satisfaction, reduces risk, and drives profitable purchases (Goldstein, Johnson, Herrmann & Heitmann, 2008). Whatever the default choices are, many people still stick with them. In the management field, default is used to control time for a meeting (Ebert & Freibichler, 2017). In an economic field, defaults can be divided into 2 groups: Mass default and Personalize default (Goldstein et al., 2008).

1) Mass default is a general default without taking customers' individual characteristics or preferences into account. Sellers will design this default in marketing when they lack information about customer's profiles or preferences. A common example can be seen in an online retailer's using standard shipping to be a default. However, the customer can actively choose fast delivery. *Benign default, forced default, random default, and hidden option* are different types of defaults in mass default.

- *Benign default* is the best guess when preference information is absent such as which product or service configurations would be most acceptable to most customers and would pose the least risk to the firm. The holder straps on Maxi-Cosi car seats is an example for this default. Which sets of holes, a lower set for newborns or a higher one for older children, should be the default? The higher strap setting could endanger a newborn, but the lower one would be uncomfortable for an older child. It is clear for the benign default in this case, which should be the lower set for newborns. The reason is most customers purchase this type of car seat for newborns and the safety risks or loosely fitting straps are more serious than the risk of uncomfortable from tight-fitting ones.

- *Forced default* is appropriate when the company wants to deny access to a product or service rather than accept the potential costs that customers who fail to agree to the terms of use might generate. This default shows at the end of registration process in many online website. The customers have to accept terms and conditions from the companies before finishing the process.

- *Random default* appropriates for a default when customers are assigned arbitrarily to one of the several default configurations. This default can help companies to reveal customers' preferences and switch using mass defaults to creating personalized ones. For example, online marketers could randomly send their emails as text and half as HTML to be the default option with links that allow recipients to switch when the customers' preferences are absent. By monitoring numbers of people who switch from each default based on the original browsers and operating systems they are using, the companies can send future emails in the default setting the current customers prefer.

- *The hidden option* is a default that is presented as a customer's only choice, although it is hard to find alternatives that exist. This option is a simple expedient for companies and causes no harm to them or their customers. This option is usually used in the computer industry such as media players and computer games. The program comes with default sounds and visual interfaces that can be changed but alternatives are not defined in the users' manual.

2) Personalize default is used to reflect individual differences and can be tailored to better meet customers' needs. Types of defaults in this group are smart default, persistent default, and adaptive default.

- *Smart default* is applied when an individual customer is known. The setting can be customized in a way that is likely to be ideal for the customer and the company. It is fit better than a mass default. For example, the smart default can adjust passenger's weight in real time to enable an airbag to deploy the right force to save her life. Configurations in the default can be opt out by the customers to reject the smart default when it cannot achieve her expectation.

- *Persistent default* is an automatic selection using the previous process. The future preference can be predicted from the past selection. For example, a seat on an airplane being automatically assigned to the passenger upon ticket purchase. The assumption of the seat comes from the past choice from the passenger.

- *Adaptive default* is the alternative based on current decisions made by a customer. It is dynamic and can update itself based on current decision that a customer has made. It is appropriated in online environments when a customer makes a sequence of choices. In web-based automobile configurations, buyers who specify that they want a high-horsepower engine may be satisfied to view a three-spoke, sporty steering wheel by default.

- *Giving feedback* is a technique that aims to warn decision makers about their poor decisions or errors. It is proposed as a solution for biased decision making, offering a warning about the possibility of bias, providing advice, the direction of bias, and offering an extended program of training with feedback, coaching, and other interventions designed to improve judgment (Milkman et al., 2009). The influence of feedback can be seen on a tournament experiment to submit a commercial logo design. Feedback from the committee can reduce the number of participants but improve the quality of subsequent submissions. It increases high-quality output, with gains in quality for outweighing the costs of the participation. The positive effects of feedback on the quality of innovation in this setting are entirely the result of improvement, rather than based on talent or luck (Gross, 2017). This feature is also used to nudge shoppers in a supermarket using embedded technologies. These technologies provide appropriate feedback with emotion about the product and provide key information when the product is scanned as shown in Figure 2.20 (Kalnikaitė et al., 2013).

Figure 2.20: An example of Feedback from NUDGES (Kalnikaitė et al., 2013)

- *Expect error* is usually applied in a design to avoid an unexpected decision error or go in the wrong direction. An example is an ATM machine. People aim to get the money from the machine and then usually forget the ATM card within the machine. Therefore, a designer changes a sequence to get the money to be after activity to get the ATM card. The main objective will complete after all activities are done.

Figure 2.21: An example of Expect error from NUDGES (Thaler & Sunstein, 1945)

- *Structure complex choices* lead decision makers to think more and think carefully. When choices become more numerous, the good choice architecture will provide the structure. Then structure will affect outcomes (Thaler & Sunstein, 1945). The example is selecting an apartment regarding only price or price, size, and accommodation as shown in Figure 2.22.

Figure 2.22: An example of Structure complex from NUDGES (Thaler & Sunstein, 1945)

Before applying a nudge to control or change decision behavior, people should assess the situation at hand or the situation that needs fast response. Then personal behaviour in workers will be focused and a nudge type is selected. After that people should design, construct, and pre-test the nudge. At the end of the implementation of evaluation, a guidance for applying the nudge is required (Lindhout & Reniers, 2017). The nudge can be defined in 4 dimensions based on purpose of application.

1) A nudge is used for controlling individual behavior or activating the design behavior standard. Self-control aims to help people to follow through with a behavior standard that they would like to accomplish but have trouble enacting such as to stop smoking. Another type aims to change behavior in the absence of a strong, pre-existing behavioral standard such as blood donation in Figure 2.19

2) A nudge is used for self-imposed or passive exposure. Self-imposed aims to enact a behavioral standard they recognize as subjectively important such as save more tomorrow. Passive exposure, on the other hand, does not require people to voluntarily seek them out. The ways that available options are presented can shape human behavior.

3) A nudge can be mindful or mindless. A nudge that requires the mindfulness of a decision maker, can help them to make more rational, cost-efficient decisions. This nudge encourages a decision maker to make decisions during a cool state of less emotion. A decision maker, therefore, has to be aware of this nudge in order to be influenced by it.

On the other hand, a mindless nudge can influence behavior by taking advantage of well-established behavior biases. This nudge uses emotion, framing, anchoring to change the decision that people make by replacing or canceling out unhelpful automatic behavior.

4) A nudge is used to encourage or discourage behavior. An encouraging nudge aims to facilitate the implementation or continuation of behavior that the Nudger believes is desirable. A discouraging nudge tries to hinder or prevent behavior that the Nudger believes is desirable.

In real applications, types of nudges are classified in different ways. Hansen and Jespersen (Hansen & Jespersen, 2013) separate types of nudges related to Type 1 (automatic thinking) vs Type 2 (reflective thinking) and transparent (a nudge provided in a way that the intention behind it) vs non-transparent (the citizen in the situation cannot reconstruct whether the intention or the means by which behavior change is pursued). Figure 2.23 shows a description of each group.

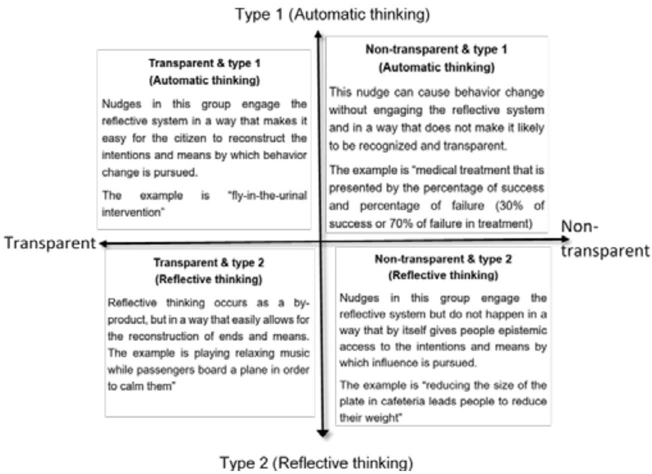


Figure 2.23: Types of nudges (Hansen & Jespersen, 2013)

This classification is modified in a safety application (Lindhout & Reniers, 2017). Types of nudges are grouped using automatic (uncontrolled, effortless, associative, fast, unconscious, skilled) vs choice (controlled, effortful, deductive, slow, selfaware, rule-following) and transparent (visible) vs non-transparent. An example of each group is shown in Figure 2.24.

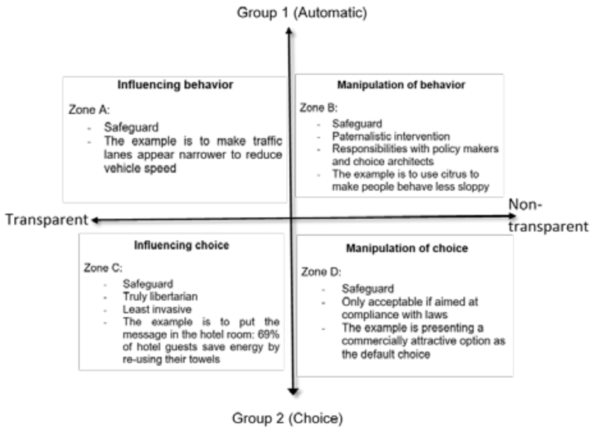


Figure 2.24: Types of nudges in a safety application (Lindhout & Reniers, 2017)

Another research group also classified nudges into 4 groups but used a different criterion. These 4 groups are divided related to responding mode and affect using automatic thinking vs reflective thinking and hot affect vs cold affect (Samson, 2014). An explanation of each group is described in Figure 2.25.

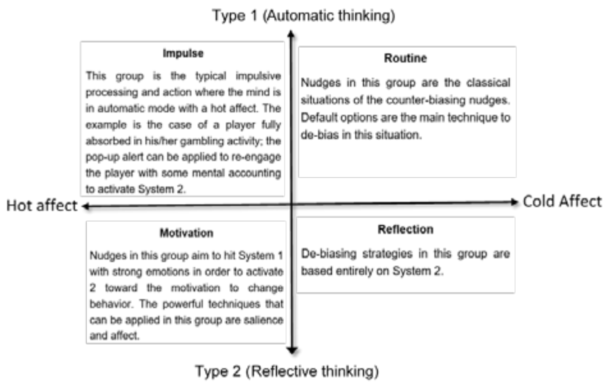


Figure 2.25: Types of nudges related to responding mode and affect (Samson, 2014)

In the design field of consumer goods, types of nudges are classified by Type 1 (automatic thinking) vs Type 2 (reflective thinking) and decisive (the nudge in the product feature is a major argument for buying the product) vs non-decisive (the nudge in the product feature is not a major argument for buying the product) (Haug, A., & Busch, J., 2014) . Each type of nudges is classified and described in Figure 2.26.

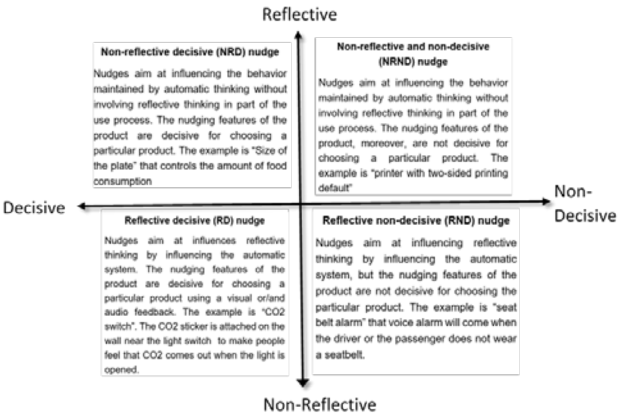


Figure 2.26: Types of nudges in the design field of consumer goods (Haug, A., & Busch, J., 2014)

Nudges can be used in different situations and in different ways to influence decision making. Interesting techniques are summarized by Sunstein (Sunstein, 2014) as the following:

1) Default rules
2) Simplification (forms and regulations), easy to underestimate
3) Uses of social norms
4) Increases in ease and convenience (makes process simpler)
5) Disclosure (comprehensible and accessible information)
6) Warning, graphic or otherwise (bold color, triggering people's attention)
7) Pre-commitment strategies (people commit to a certain course of action)
8) Reminders (by email or text message, prompted choice)
9) Eliciting implementation intention (emphasizing people's identity can be effective)

Not only different techniques possibly influence decision behavior in a different way, but the personal characters are also related to the influence of nudges (Lindhout & Reniers, 2017). Individual attitudes towards a behavior, skills, ability and individual knowledge, and personal characteristics such as risk perception can provide different results of decision making with the same nudge.

Nudges provide many advantages to control decision behavior in the design direction. Nudges can also cause a boomerang effect or influence the decision making in an unexpected direction.

For example, there is a policy to provide ‘smileys’ as a reward for desired behavior of the households who consume energy lower than the average consumption, and ‘frown’ to reprimand non-desired behavior for the households who consume energy higher than average consumption.

From this policy, the households whose energy consumption is lower than the average, may begin to consume more because their bias of being a good citizen may be triggered (Schultz, Nolan, Cialdini, Goldstein & Griskevicius, 2007).

Another method that is similar to a nudge but has more components, is called “MINDSPACE” (Dolan et al., 2012). This method also aims to increase awareness of the effects of similar heuristics. Components in MINDSPACE that are similar to nudge are Incentive (I) and Default (D). Others are Messenger (M), Norms (N), Salience (S), Priming (P), Affect (A), Commitment (C), and Ego (E) (Rainford & Tinkler, 2011).

- *Messenger* or the person who communicates information and can influence the decision maker to believe or not believe in something. If you respect that person, you will heavily believe in his/her opinion and follow him/her.

- *Norms* are quite similar to social bias. Our decisions or behaviors usually come from a social or group’s decision and behavior. People try to avoid a mistake by following what other people have already done, which can be also seen as a trend.

- *Salience* influences a decision by finding a thing that is relevant to a decision maker. This technique uses a decision maker’s personality and experience to influence a decision. An example is providing key information when scanning the product (Kalnikaitė et al., 2013).

- *Priming* is a technique to stimulate sub-conscious cues without conscious guidance or intention. The prime consists of meaning (e.g. words, colors) that activate associated memories (e.g. schema, stereotypes, and attitude) (Tulving, Schacter &

Stark, 1982). This is called process priming. The example is using red color for a warning or a dangerous sign. Conceptual priming, on the other hand, does not rely on activating meaning, such as perceptual priming, the mere exposure effect, affective priming (Murphy & Zajonc, 1993), or the perception-behavior link (Chartrand & Bargh, 1999).

- *Affect* is our emotion association that can powerfully shape our actions. When integrating affect in judgment and decision making, this can act as information (Beresford & Sloper, 2008). Feelings about a choice are information that guide decision making and can shape the value of an alternative. Individuals are more likely to recall information from memory that is congruent with their current feeling (Schwarz, 2000). People can compare good and bad feelings rather than attempting to integrate a mass of conflicting logical reasons in more complex decisions.

- *Commitment* or pre-commitment is often used as a tool to counteract people's lack of will power and to achieve behavior change. Individuals are motivated to maintain a consistent and positive self-image (Cialdini, 2009), and they are likely to keep a commitment to avoid reputational damage (if they are made publicly) and/or cognitive dissonance (if they are made privately) (Festinger, 1962). In management, commitment is used to reduce underestimation or optimism bias such as the time needed to complete a future task (Ebert & Freibichler, 2017).

- *Ego* is the last component in MINDSPACE. It uses the advantage of good feelings about ourselves to make a decision. People seems to act in the direction that make them feel good about themselves. One example comes from Step Jockey's mobile app. Real feedback for users on number of steps climbed and an equivalent measure calories used fills people's egos. This app can lead a third of people to start taking the stairs in other places.

Even some components in NUDGES and MINDSPACE are different; these different components have a similar objective. For example, understand mapping and giving feedback in NUDGES require translation in terms of a single most salient that is a component in MINDSPACE. Expect error can also use default or priming (Dolan et al., 2012). Therefore, components in NUDGES and MINDSPACE can be seen as the technique to change human behaviors and avoid cognitive biases.

2.5.5 Stages of success for cognitive de-biasing

Croskerry (Croskerry, Singhal & Mamede, 2013) proposed 7 steps to evaluate the successful of cognitive de-bias, which can be described by the transtheoretical model of change as shown in Figure 2.27.

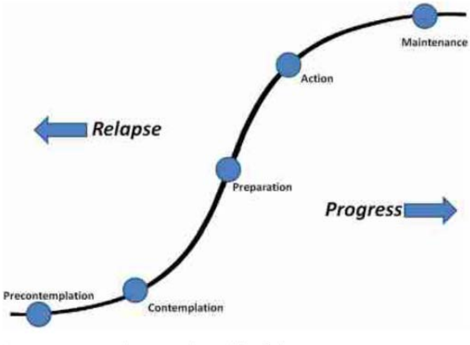


Figure 2.27: Transtheoretical model of change

The success of cognitive de-biasing can defined in different stages, which are

- Lack of awareness of bias: the decision maker does not necessary to be aware of correct approaches to make decisions
- Awareness of bias: de-biasing will be successfully addressed, an awareness and motivation for change are needed
- Ability to detect bias: The decision maker is aware of the direction of bias but he still cannot shake the conviction of his biased judgement
- Considering a change: The decision maker can distinguish the different of decision with and without biases.
- Deciding to change: The decision maker decide to follow the direction of decision that is not influenced by biases.
- Initiating strategies to accomplish change: Strategies and methods to avoid decision biases are investigated and identified to avoid the direction of making decision biases
- Maintaining the change: The decision maker can keep making a decision without bias in the same situation.

However, most of decision makers are unaware of the powerful influence of unconscious factors on their reasoning and may not realize an affective of biases in their decision making. Therefore, they see no reason to take any action to change their thinking.

2.5.6 Tools to support decision making

In the digitalization world, many technologies are developed to support decision making via applications and tools, which support a specific task and a general task (Luft, T., Lamé, G., Ponn, J., Stal-Le Cardinal, J., & Wartzack, S, 2016). *Choicemap* is an application to help a decision maker make better decision. For example, using this app in the medical treatment. Questions about the patient's situations and preferences are added in the app. Then the app will suggest the treatment and provide more information about the treatment that is appropriate to the patient.

Decision Buddy is an application that is used for finding a popular vote by creating a situation, choice, and participation. Everyone is then invited to vote using the app. The final solution is tallied and announced via app on mobile devices. This application is suitable for general tasks. It is now available in Google Play from Android.

Another application to support decision making is Best decision. Decision makers can make a choice by comparing the criteria provided, filtering the important data, selecting choices, then giving the statistics related to criteria. The app will then calculate all information and rank alternatives to suggest the appropriate solution. This app is also now available on the OS platform.

Different applications have been developed based on different algorithms and functions to support decision making and organize results. Table 2.8 summerized types of algorithms that are usually applied in the application such as Multicriteria Optimization (MODA)/Multi-attribut utility theory (MAUT), and Analytic Hierarchy Process (AHP).

Table 2.8: Available decision applications with algorithms (Oleson, 2016)

Product	Decision Algorithms Implemented		
	MODA/MAUT	AHP	Other
@RISK	n	n	
1000Minds	y	n	PAPRIKA
Analytic Solver Platform for Excel	n	n	
Analytica	y	n	
AnalyticSolver.com	n	n	
ChemDecide	y	y	MARE, ELECTRE III
D-Sight CDM	y	y	PROMETHEE
DEA SolverPro	n	n	Data Envelopment Analysis
DecideIT	y	n	The Delta decision library for imprecise information
Decision Explorer	n	n	
Decision Quality Desktop (including DTrio and TreeTop)	y	y	User definable decision metrics
DiscoverSim	n	n	Monte Carlo Simulation
DPL	y	n	Decision Tree roll-back using expected values, Monte Carlo simulation, Multi-agent
Equity3	y	n	
FOCUS	y	n	
GoldSim	y		
Hiview3	y	n	MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique)
Intelligent Decision System (IDS)	y	y	Evidential Reasoning appraoch
Logical Decisions v7.2	y	y	
MeenyMo	y	n	PAPRIKA
SensIt	n	n	Automated Sensitivity Analysis: One-Way Tornado and Spider; Two-Way Tornado
SilverDecisions	y	n	
SimVoi	n	n	Automatically determines value of information for uncertain input variables
SLIM	n	n	MJC2 in-house algorithms
Smart Decisions	y	n	
Smart-Swaps	n	n	Even swaps method
The DecisionTools Suite	n	n	
TransparentChoice	n	y	
TreePlan	n	n	Decision tree rollback using expected value or risk utility
Web-HIPRE	y	y	Various MAVT weighting techniques

Table 2.9 summarizes functions that usually appear in available decision applications. Based on information from these two tables, most decision applications have been developed using Multicriteria Optimization (MODA)/Multi-attribut utility theory (MAUT), and Analytic Hierarchy Process (AHP). These algorithms have a pairwise-comparison algorithm to be a fundamental algorithm for processing and analyzing the result. Additional functions that may usually be implemented in the decision application are group elicitation, exporting results or/and database, criteria and attribute weighting and data security function.

Table 2.9: Available decision applications with different functions

Product	Tools for group elicitation	Import (e.g., database, spreadsheet)	Export (e.g., presentation graphics, data)	Criteria / attribute weighting	User can protect data from other users
@RISK	n	y	y	y	y
1000Minds	y	y	y	y	y
Analytic Solver Platform for Excel	n	y	y	n	y
Analytica	y	y	y	y	y
AnalyticSolver.com	n	y	y	n	y
ChemDecide	n	y	y	y	y
D-Sight CDM	y	y	y	y	y
DEA SolverPro	n	y	y	y	y
DecideIT	n	y	y	y	n
Decision Explorer	y	y	y	n	y
Decision Quality Desktop (including DTrio and TreeTop)	y	y	y	y	n
DiscoverSim	n	y	y	n	y
DPL	n	y	y	y	n
Equity3	n	y	y	y	n
FOCUS	y	y	y	y	y
GoldSim	n	y	y	n	y
Hiview3	n	n	y	y	y
Intelligent Decision System (IDS)	n	y	y	y	n
Logical Decisions v7.2	y	y	y	y	n
MeenyMo	n	y	n	y	y
SensIt	n	y	y	n	y
SilverDecisions	n	n	y	y	n
SimVoi	n	y	y	n	y
SLIM	n	y	y	y	y
Smart Decisions	y	y	y	y	n
Smart-Swaps	n	n	n	n	y
The DecisionTools Suite	n	y	y	y	y
TransparentChoice	y	y	y	y	y
TreePlan	n	y	y	n	y
Web-HIPRE	y	n	n	y	y

There are some applications and tools to support decision making, which are still in the research. The mobile app for purchasing products is developed by Kalnikaite (Kalnikaitė et al., 2013) is one application that aims to support shoppers when buying products. This app provides links to websites that contain additional product details and users review using star rate and price comparisons as the primary decision-making anchors when scanning the barcode on the product. When the shoppers buy groceries in the supermarket and purchase more expensive one-off items, relevant and useful product information in apps are used. The star rate in the app can further influence participants' purchase decisions to confirm or support the decision. An example of this application is shown in Figure 2.28.

Figure 2.28: An example of mobile application for purchasing product (Kalnikaitė et al., 2013)

A planning tool is another application in the research that intends to support a decision maker to make better planning (Jankovic et al., 2009). This tool proposes a plan of actions or tasks to decision makers. They are adapted for the transformations view that contains information of tasks before and after decision-making, deliverables necessary for good decision-making and important in the implementation, responsibility assignment, etc. This application requires the objectives in collaborative decision-making processes and their relationships to provide a plan of actions or tasks. Even though each tool and application has different functions and algorithms to support decision making, all of them aim to increase the performance of decision making.

Aydin proposed two different ways to evaluate the performance of decision support. (Aydın, 2006)

1) Effect: this is an assessment of decision support regarding what has happened to the decision-making process being supported. The relevant questions are “when do decision makers find decision support useful?”, and “when do they find it bothersome?”
2) Effectiveness: this indicates examining decision support regarding its objectives. The relevant questions are “how effective is decision support at accomplishing its objective?”, and “does the cost of learning the provided support exceed the benefits when using it?”

2.6 Conclusion

Decision making is one of many interesting topics for many researchers from different fields. They aim to understand and explain the processes of decision making in different situations such as slow and fast thinking. Moreover, handling and controlling decisions are also broadly investigated and developed such as NUDGES and MINDSPACE. Production engineering is also another field that requires a potential method to support decision making including systematic decision and heuristic decision during the product development process. Many methods and tools have been developed to support decision making, but only some of them are applied in the real situation. Results from this chapter show that investigating and improving decision making is still required in the research, especially in product development that decision is the main part to indicate the direction of a new product.

3 Research objective and methodology

After finding the scope of interesting research's topic and searching for more information and knowledge from the literature, the main focuses including research objective, research question, and research methodology are presented in this chapter.

3.1 Research objectives

Decision making is an important activity in product development. The success of developing a new product generation requires good and high potential decision making. People do not always base their choices only on a systematic decision. An intuitive decision can also take the main part for a problem-solving activity and solution selection, especially in uncertainty situations and insufficient information. However, these 2 decisions cannot be directly separated. People in product development do not base their decision only on one option. They try to use both decision methods to find the solution.

The simple logic called heuristic then comes to take a main part in the decision making. Even if a heuristic decision is usually used to solve a complex decision in a simple way with a high potential result, this can also be misleading due to the influence of cognitive biases.

The research about heuristic decisions and biases in product development is rare and lack of details. Most research proposed heuristic decisions in the direction of supporting decision making such as the fast and frugal heuristic. Some researches provided guidelines and hints about heuristic decisions and biases in organization and design. However, information about heuristic decisions and biases in general activities of product development, such as the decision situation, characters of biases, results of biases, is rarely investigated and described. Moreover, potential techniques to reduce or avoid these biases in product development are rarely explained. Therefore, this research is proceeded based on 2 objectives:

Objective 1:

Understand and investigate the appearance of heuristic decisions and cognitive biases in activities of product development, especially when prioritizing alternatives and selecting the solution.

This research focuses on heuristic decisions that provide cognitive biases. Therefore, heuristics under ecological environment are not described in this research. Intuition is a key factor in many activities of product development such as evaluating alternatives and selecting the solution when the information is not available or insufficient. Therefore, this is a good environment to start searching and investigating heuristic decisions in product development. Knowledge and results from this phase can then be applied in the whole problem-solving activity and all steps in the product development process.

Objective 2:

Investigate, develop and apply potential strategies to support decision making and improve decision errors based on unawareness from decision makers using different de-biasing techniques in the product development when encountering heuristic decisions and biases.

After understanding the heuristic decisions and biases in product development, available techniques/strategies/tools from the general applications are developed and applied to support and reduce decision biases in product development. This objective aims to support both researchers and developers to understand the basic idea of de-biasing techniques and can also develop their own tools to avoid decision biases in a specific situation in the whole product development process.

3.2 Research questions

Based on the research objectives and research hypotheses, research questions are formulated to identify the direction of research and achieve research objectives.

Question 1:

How can heuristic decisions and biases influence decision making in product development?

Question 2:

Which available techniques can be developed and applied to handle heuristic decisions and biases?

Question 3:

How can those techniques handle heuristic decisions and biases in product development?

To answer these questions and achieve the objectives, a suitable procedure and method are required to support this research.

3.3 Research methodology

3.3.1 Fundamental knowledge of research methodology

A research methodology is the specific procedures or techniques that have to identify, select, process, and analyze information about a topic (van den Heever). Many researchers struggle with selecting an appropriate method to begin and continue the research. Some researchers select the wrong methods in the research. And some researchers proceed with the research based on their preferences. These situations can lead to failure or unsuccessful research, spending overtime unproductively. Therefore, it is imperative to design and organize research methodology before starting the research.

The framework called DRM-Design Research Methodology (Blessing & Chakrabarti, 2009) has a guideline for researchers to select and apply a suitable approach and appropriate methods in the research. The design research methodology can provide understanding and support to help improve design research. The framework of DRM is shown in Figure 3.1.

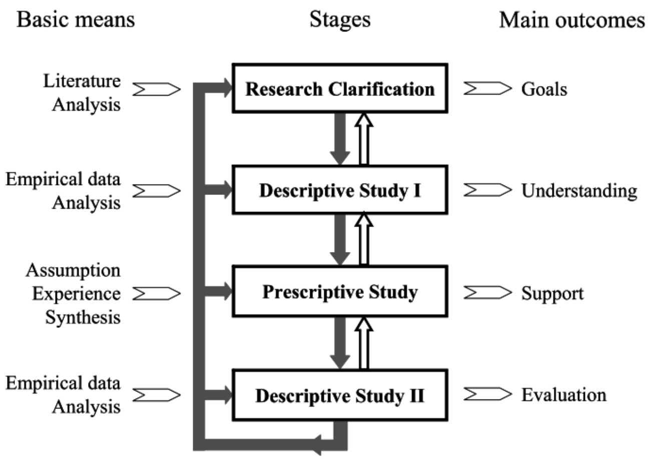


Figure 3.1: DRM framework (Blessing & Chakrabarti, 2009)

The ***research Classification (RC)*** is the stage where the literature is reviewed to find some evidence or information to support their assumptions in order to formulate a realistic and worthwhile research goal. In the ***Descriptive Study I (DS-I)***, the description detailed is made to determine which factors should be addressed to improve task clarification as effectively and efficiently as possible. Evidence in the literature is not clear enough to determine the important factors. Therefore, methods such as observing and interviewing at work are required to obtain an understanding of the existing situation before moving to the next step. This step can be seen as an analysis of the empirical data step. The next stage is the ***Prescriptive Study (PS)*** that aims to increase an understanding of the existing situation. The researchers will develop various possible scenarios by varying the targeted factor and try to improve the quality of the problem definition. After understanding the various interconnected influencing factors in DS-I, a design methodology is selected to encourage and support problem definition. The first evaluation of this actual support is then developed. The last stage called ***Descriptive Study II (DS-II)*** is the stage to investigate the impact of the support and its ability to realize the desired situation. The study in this research is used to evaluate the applicability of the support and the usefulness. Other several effects that had not anticipated are also observed. In the end, the research concept is concluded; and further investigations of the existing situation are proposed and suggested. A revisit of the DS-I stage is then recommended. It is useful to start planning the evaluation of support (DS-II) during the development of the support (PS) in order to be able to determine which parts of the support required to be developed regarding the desired evaluation. However, these stages are not necessary to appear in every research. Figure 3.2 shows 7 possible types of design research regarding the DRM framework.

Research Clarification	Descriptive Study I	Prescriptive Study	Descriptive Study II
1. Review-based →	Comprehensive		
2. Review-based →	Comprehensive →	Initial	
3. Review-based →	Review-based →	Comprehensive →	Initial
4. Review-based →	Review-based →	Review-based → Initial/ Comprehensive ←	Comprehensive
5. Review-based →	Comprehensive →	Comprehensive →	Initial
6. Review-based →	Review-based →	Comprehensive →	Comprehensive
7. Review-based →	Comprehensive →	Comprehensive →	Comprehensive

Figure 3.2: Seven possible types of design research (Blessing & Chakrabarti, 2009)

A review-based study is based on a review of the literature. A comprehensive study consists of a literature review and a study in which the results are produced by the researcher such as an empirical study, develops support, or evaluates support. An initial study will close a project and involve the first few steps of a particular stage to show the consequences of the results. These results are prepared for other steps. In the doctoral research, the first four types of research project in Figure 3.2 are suitable based on time and resources. Type 5 and type 6 are usually appeared in the initial plans of the doctoral research but are not achieved because of limited time and resources. Type 7 is more common for the work of a research group or when a problem with a very specific scope is defined. Table 3.1 summarizes potential methods and descriptions in the descriptive study and prescriptive study that are possibly applied in this research.

Table 3.1: Summarized methods and descriptions in the descriptive and prescriptive study that are possibly applied in this research

Methods in the descriptive study	
Method	**Description**
Observation Pure observation Participant observation Observing participant	Recording what is actually taking place either by hand or using recording or measuring equipment A researcher is not involved in the process A researcher participates in the process A researcher is designing and observes and documents their own research
Simultaneous Verbalisation	Participants speak aloud while working/ cognitive behavior that cannot be obtained through normal observation
Experiments Quasi-experiment Non-experiment	A researcher has control over the context in which the phenomena to be studied The researcher has less control over the experiment than the classic experiment A single group from pre-test, 2 non-equivalent groups in post-test
Case study	Describe a study that involves data from a real setting
Collecting documents	Retrieve documents related to a particular project, topic or product from a variety of sources
Questionnaires	Collect thoughts, beliefs, options, reasons from people by asking question
Interviewing	The purpose is similar to the questionnaire but is done carried out face to face.
Action research	Introducing and evaluating change, originally in organizations and programs, but increasingly in design (duals aim of action and research)
Methods in the prescriptive study	
Method	**Description**
Literature search	Find published information that can be useful
Classification of design information	Split a design problem into manageable parts (this should help solve the problem as well as help modularise the support)
Design specification procedure	Specify the requirements by listing, analyzing and editing objectives

3.3.2 Research methodology in this research

This research is proceed following the DRM framework in research type 3. Some methods in Table 3.1 was selected in each framework based on available resources and objectives. The DRM framework regarding this research and selected methods in this research is shown in Figure 3.3.

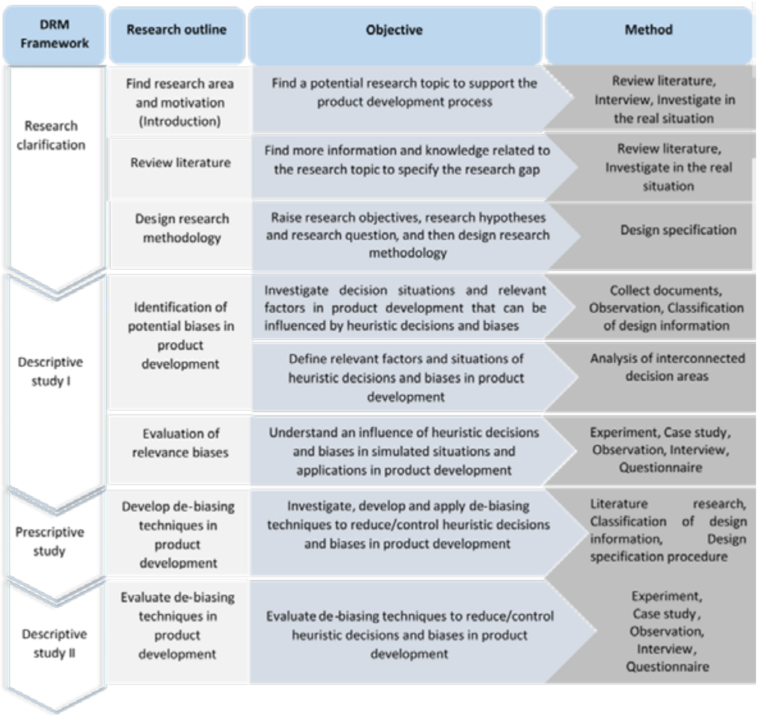


Figure 3.3: DRM framework in this research

Information from the literature is a basic knowledge to start this research. Design experiments and investigation from the real situation are performed with students in a lecture and Live Lab to confirm and ensure assumptions and conceptual ideas. IPEK has cooperation with many partner companies such as Porche, Mahle, and Stirl that are also suitable to retrieve information from the real environment. Based on these resources, experiments can be done by interview, observation, and questionnaire.Activities in each study will be performed to answer different questions and achieve objectives. Sub-questions in each study based on the DRM framework in Table 3.2 are then proposed to scope the research and proceed it in an effective direction.

Table 3.2 Sub-research questions based on the main research questions in Section 2.2 and DRM framework

Main research question	How can heuristic decisions and biases influence decision making in product development?	Which available techniques can be developed and applied to handle heuristic decisions and biases?	How can those techniques handle heuristic decisions and biases in product development?
DRM framework	Descriptive study I	Prescriptive study	Descriptive study II
Sub-question	- Which components are related to heuristic decisions and biases in product development? - Which decisions are made in product development? - Which heuristic decisions and biases can happen in decision making? - Which decision situations are made by heuristic decisions in product development, especially in solution selection in the front end phase? - Which methods are used to support decision making? - What are the possibilities that heuristic decisions and biases appear in product development based on different techniques to make a decision in solution selection in the front end phase? - How can those possibilities happen?	- Which strategies/techniques can be used to control/handle heuristic decisions and biases? And how? - How can those strategies/techniques be applied/implemented to control/handle heuristic decisions and biases in product development?	- Which environments in design experiments are suitable to evaluate techniques/strategies to control/handle heuristic decisions and biases in product development? - How can those strategies control/handle heuristic decisions and biases in product development?

3.4 Conclusion

This research is performed based on the research objectives, research hypotheses, and research questions as described in this section. The DRM framework including the descriptive study I, the prescriptive study, and the descriptive study II are used to proceed with this research. To scope down the work to achieve objectives in this research, sub-questions are raised based on the DRM framework. This research is, therefore, performed to answer sub-questions in each type of research study using different methods such as literature review, observation, interview, and questionnaire.

Seven sub-questions in descriptive study I will be answered in Section 4; and 1 sub-questions in the same study will be answered in Section 5. Sub-questions in prescriptive study and in descriptive study II will be answered in Section 6 and Section 7, respectively. Results from sub-questions in the descriptive study I, prescriptive study, and descriptive study II will answered the first, the second, and the third questions in the research questions, consequently. Therefore, all questions will be answered after these 3 studies are performed.

4 Identification of potential biases in product development

Decision making in product development is usually explained in terms of rational decision-making and methods to support decision making. Decision biases in product development are not usually described and clarified. At the beginning of this research, therefore, the researcher would like to investigate general decision-making in product development based on the literature review in Section 2.2. Then different biases from different fields such as psychology and economics are summarized and classified. After that, decision situations that required heuristic decisions are collected based on the investigation, observation, and interview. The last component in the decision-making process is the method to support decision making in solution selection, which is collected from literature and classified in different groups based on characters of the methods. At the end of this chapter, possible connections in each component: heuristic decisions, biases, methods, are illustrated and explained. Each study in Table 4.1 is conducted to answer sub-questions as mentioned in Section 3.2 in the descriptive study I.

Table 4.1: Overview of investigation to answer different questions

Sub-chapter	**Question**
4.1 Decision making in product development	Which decisions are made in product development?
4.2 Heuristic decisions and biases in decision making	Which heuristic decisions and biases can happen in decision making?
4.3 Heuristic decisions in product development, especially in solution selection in the front end phase	Which decision situations are made by heuristic decisions in product development, especially in solution selection in the front end phase?
4.4 Supporting methods for solution selection and decision making	Which methods are used to support decision making?
4.5 Possibility of heuristic decisions and biases in product development	What are the possibilities that heuristic decisions and biases appear in product development based on different techniques to make a decision in solution selection in the front-end phase?

4.1 Decision making in product development

Decision making always happens in the whole product development as explained in the literature review. Decision making can be defined based on a management activity and an engineering activity. Types of decisions are varied based on departments and roles in product development. Many researchers focus on the processes of decision making and methods/strategies to support decision making. Specific decisions are not usually described. At the beginning step of this research, the researcher then defines specific decisions from different literature by modifying situations that are explained in some researches to be questions and also summarizing available decisions in literature.

Thirty three decisions are described directly in Seram's literature review (Seram, 2013), which are classified into 8 groups: concept development, supply chain, product design, performance testing and validation, production ramp-up and launch, product strategy and planning, product development and organization, and project management (Seram, 2013). Even though other papers did not directly specify types of each decisions regarding activities in product development. They explain characters of decision making in different activities that can also be summarized and classified in 8 groups from Seram's paper. Some decisions are similar to the decisions that are proposed by Seram, but some are new. Table 4.2 shows decisions in 8 groups from 10 reference papers.

Table 4.2: Decisions in product development based on 9 activities

No	Decisions	Activities	References
1	What is the core product concept?	Concept development	(Arntz, S., Verbaan, R., Eisenbart, B., & Cardoso, C., 2017)
2	What are the target values of the product attributes, including price?	Concept development	(Seram, 2013)
3	What is product architecture?	Concept development	
4	What variants of the product will be offered?	Concept development	
5	Which components will be shared across which variants of the product?	Concept development	
6	What will be the overall physical form and industrial design of the product?	Concept development	

No	Decisions	Activities	References
7	Which components will be designed and which will be selected?	Supply chain design	
8	Who will design the components?	Supply chain design	
9	Who will produce the components and assemble the product?	Supply chain design	
10	What is the configuration of the physical supply chain, including the location of the decoupling point?	Supply chain design	
11	What type of process will be used to assemble the product?	Supply chain design	
12	Who will develop and supply process technology and equipment?	Supply chain design	
13	What are the values of the key design parameter	Product Design	
14	What is the configuration of the components and assembly precedence relations?	Product Design	
15	What is the detailed design of the components, including material and process selection?	Product Design	
16	What is the prototyping plan?	Performance Testing and Validation	(Seram, 2013)
17	What technologies should be used for prototyping?	Performance Testing and Validation	
18	What is the plan for market testing and launch?	Production Ramp-Up and Launch	
19	What is the plan for production ramp-up?	Production Ramp-Up and Launch	
20	What is the market and product strategy to maximize the probability of economic success?	Product Strategy and Planning	
21	What portfolio of product opportunities will be pursued?	Product Strategy and Planning	
22	What is the timing of product development projects?	Product Strategy and Planning	
23	What, if any, assets (e.g., platforms) will be shared across which products?	Product Strategy and Planning	
24	Which technologies will be Product Development Organization employed in the product(s)?	Product Strategy and Planning	
25	Will a functional, project, or matrix organization be used?	Product Development Organization	
26	How will the team be staffed?	Product Development Organization	

No	Decisions	Activities	References
27	How will project performance be measured?	Product Development Organization	(Seram, 2013)
28	What will be the physical arrangement and location of the team?	Product Development Organization	
29	What investments in infrastructure, tools, and training will be made?	Product Development Organization	
30	What type of development process will be employed (e.g., stage-gate, sprints, etc.)?	Product Development Organization	
31	What is the relative priority of development objectives?	Project Management	
32	What is the planned timing and sequence of development activities?	Project Management	
33	What are the major project milestones and planned prototypes?	Project Management	
34	How much is a success rate on a new product?	Product Development Organization	(Åstebro & Elhedhli, 2006)
35	Which project can be further developed in the next step	Project Management	(Albar, 2013)
			(Catherine Louis, 2016)
37	Which project has an innovation?	Project Management	(Mathews, 2010)
38	What is a risk identification in the front end phase of construction projects by an expert?	Project Management	(Maytorena, Winch, Freeman & Kiely, 2007)
36	What are the product development crises in product design?	Product Design	(Muenzberg, C., Stingl, V., Geraldi, J., & Oehmen, J., 2017)
40	Which material should be used for the product?	Product Design	(Radu Fotolescu, 2017)
39	Who should work in which position in a team?	Project Management	(Catherine Louis, 2016)
41	How much a project cost?	Project Management	(Virine et al., 2018)
42	Where are human resources and suppliers?	Project Management	

Results from Table 4.2 show the decisions that usually appear in each activity of product development. Details and complexity of decisions have many variety depends on available information and environment. Some decisions can be made based on information from previous projects. Some decisions can be made based on the information in the market. And some decisions require experience from an expert to be made. However, all answers for these decisions in the project can lead the direction of product development into different ways. These 42 decisions are only examples of visible decisions in product development. There are still many decisions that appear in product development that are also important for a successful new product but do not explicit in a visible way. These decisions for examples are relevance to competitors, product analysis, and marketing. Results from this task is the beginning step of this research to get a concept idea about the decision making based on different activities in product development. Therefore, investigating and defining heuristic decisions regarding each activity in product development is an approach that should be followed in this research.

4.2 Heuristic decisions and biases in decision making

As described in the literature review, heuristic decisions can provide both a positive and negative effect on decision making. This research focuses on the heuristic decisions that provide decision biases or lead decision making in a negative direction. Three fundamental heuristic decisions proposed by Tvesky and Kahneman are representativeness, availability, and anchoring/adjustment. These heuristics were explained in details in Section 2.4. Other heuristics are then presented after these 3 heuristic decisions, which is over 100 heuristics.

However, all heuristic decisions and biases cannot be investigated in this research. The researcher, therefore, analyses resources of these heuristic decisions and biases and then classifies them into 3 groups. These groups are possible to represent different characters of all heuristic decisions and biases as mentioned in the literature. The resource of bias can stem from the decision maker, the environment, or the choice structure. These resources are identified from the author's perspective.

Heuristic decisions and biases are classified into the first group that has a resource of bias from the decision maker when they usually happen based on the experience, preference, and memory. Different decision makers can make a different decision even similar alternatives are presented. An example of heuristic decisions and biases in this group is the availability heuristic.

The second group is heuristic decisions and biases that happen from the environment such as time, social group, and information. The decision maker sometimes tries to make a decision that is the same decision as a group‘s decision to avoid taking a risk, which can be seen in the bandwagon heuristic. The different initial information can also cause a variety of decisions. The example is the anchoring heuristic.

The last resource of heuristic decisions and biases from the third group is the choice structure. An example of this group is the framing effect. The decision maker can make a different decision based on the way alternatives are presented such as loss-gain alternatives and advantage-disadvantage alternatives. No matter who makes a decision, the final decision is most similar for all decision makers.

When analysing an appearance of heuristic decisions and biases in product development, most of them originate from the decision maker such as confirmation bias, planning fallacy, and information avoidance. For example, the decision maker usually has a favorite alternative or idea and tries to find information that supports his/her idea. Some information that does not support his/her idea is discarded. The planning fallacy appears in management activity. The decision maker has a wrong decision in the project deadline and budget by underestimating the amount of work. This error also comes from an overconfidence heuristic. Anchoring and adjustment and representativeness heuristic caused by the environment are likewise significantly appeared in product development. For example, the information from the previous project or the market is the main resource of decision making. An inappropriate or insufficient adjustment can make a wrong estimation or planning in the project management. However, the heuristic decisions and biases from the choice structure are not usually presented in product development. One heuristic decision that can be seen is the framing effect. Reviewing alternatives from only one side can affect a decision to select or reject the alternative. This bias also limits the innovative idea for a new product because of focusing on the negative aspect.

Based on the concept idea of analysing heuristic decisions and biases in product development by focusing on the resource of biases, 139 heuristic decisions and biases in the database are classified into 3 groups based on resources of heuristic decisions and biases as mentioned in the previous part. . Seventy one heuristic decisions and biases have a resource of bias from the decisions maker. Forty four heuristic decisions and biases are caused by the environments. The rest of them are originated by the choice structure. These heuristic decisions and biases are collected from different resources and research fields. Only some of them were explained in the paper related to the decision making in product development. Therefore, the heusitic decisions and biases that were explained in the paperrelated to product development are summerized in Table 4.3-Table 4.5 regarding the sources of biases. Other general heuristic decisions and biases will be shown in Table A.1-A.3 in Appendix A.

Table 4.3: Heuristic decisions and biase that are caused by the decision maker and appear in the papers related to product development and management

No	Biases	Description	Product development paper
1	Availability heuristic	The tendency to overestimate the likelihood of events with greater "availability" in memory, which can be influenced by how recent the memories are or how unusual or emotionally charged they may be.	(Gino & Pisano, 2008) (Virine et al., 2018), (Montibeller, G., & von Winterfeldt, D., 2015), (Jansen & Aelen, 2015)
2	Confirmation bias	The tendency to search for, interpret, focus on and remember information in a way that confirms one's preconceptions.	(Catherine Louis, 2016; Gino & Pisano, 2008; Hammond, Keeney & Raiffa, 1998; Jansen & Aelen, 2015; Radu Fotolescu, 2017; Virine et al., 2018)
3	Conservatism (belief revision)	The tendency to revise one's belief insufficiently when presented with new evidence.	(Gino & Pisano, 2008)
4	IKEA effect	The tendency for people to place a disproportionately high value on objects that they partially assembled themselves, such as furniture from IKEA, regardless of the quality of the end result.	(Catherine Louis, 2016; Girling, 2012; Mike Pinder, 2017)
5	Illusion of control	The tendency to overestimate one's degree of influence over other external events.	(Gino & Pisano, 2008; Jansen & Aelen, 2015; Montibeller, G., & von Winterfeldt, D., 2015)
6	Information bias	The tendency to seek information even when it cannot affect action.	(Catherine Louis, 2016; Gino & Pisano, 2008; Jansen & Aelen, 2015; Mike Pinder, 2017; Virine et al., 2018)
7	Information avoidance	Situations in which people choose not to obtain knowledge that is freely available.	(Gino & Pisano, 2008)
8	Optimism bias	The tendency to be over-optimistic, overestimating favorable and pleasing outcomes (see also wishful thinking, valence effect, positive outcome bias).	(Girling, 2012)
9	Overconfidence effect	Excessive confidence in one's own answers to questions. For example, for certain types of questions, answers that people rate as "99% certain" turn out to be wrong 40% of the time.	(Gino & Pisano, 2008; Virine et al., 2018)

No	Biases	Description	Product development paper
10	Planning fallacy	The tendency to underestimate task-completion times.	(Gino & Pisano, 2008; Hammond et al., 1998), (Mike Pinder, 2017),(Virine et al., 2018)
11	Status quo bias	The tendency to like things to stay relatively the same (see also loss aversion, endowment effect, and system justification).	(Girling, 2012; Hammond et al., 1998; Mike Pinder, 2017; Virine et al., 2018)
12	Sunk costs fallacy	When they continue a behavior or endeavor as a result of previously invested resources (time, money or effort). For example, individuals sometimes order too much food and then over-eat just to “get their money's worth”.	(Catherine Louis, 2016; Gino & Pisano, 2008; Hammond et al., 1998)

Table 4.4: Heuristic decisions and biases that are caused by the environment and appear in the papers related to product development and management

No	Biases	Description	Product development paper
1	Anchoring or focalism	The tendency to rely too heavily, or "anchor", on one trait or piece of information, when making decisions (usually the first piece of information acquired on that subject)	(Gino & Pisano, 2008; Girling, 2012; Hammond et al., 1998; Mike Pinder, 2017; Montibeller, G., & von Winterfeldt, D., 2015; Virine et al., 2018)
2	Bandwagon effect	The tendency to do (or believe) things because many other people do (or believe) the same. Related to groupthink and herd behavior.	(Catherine Louis, 2016; Mike Pinder, 2017; Radu Fotolescu, 2017)
3	Hard–easy effect	Based on a specific level of task difficulty, the confidence in judgments is too conservative and not extreme enough	(Gino & Pisano, 2008; Girling, 2012)
4	Illusory correlation	Inaccurately perceiving a relationship between two unrelated events.	(Gino & Pisano, 2008)
5	Loss aversion	The disutility of giving up an object is greater than the utility associated with acquiring it (see also Sunk cost effects and endowment effect).	(Girling, 2012; Mike Pinder, 2017; Virine et al., 2018)
6	Representativeness	Representativeness is defined as the level of how well or how accurately something reflects upon a sample.	(Gino & Pisano, 2008; Virine et al., 2018)

Table 4.5: Heuristic decisions and biases that are caused by the choice structure and appear in the papers related to product development and management

No	Biases	Description	Product development paper
1	Framing effect	Drawing different conclusions from the same information, depending on how that information is presented	(Girling, 2012; Hammond et al., 1998; Mike Pinder, 2017)

Results from these 3 tables show that heuristic decisions and biases in product development can be caused by 3 resources that are the decision maker, the environment and the choice structure. Understanding an appearance of heuristic decisions and biases based on these 3 resources can be a solution to study them in this research. Moreover, these resources are the main part to deal with heuristic decisions and biases in product development.

4.3 The heuristic decision in product development, especially in solution selection in the front end phase

In Section 4.1, specific decisions in product development from the literature were listed. However, the specific heuristic decisions were not identified in the literature. An investigation of heuristic decisions is then required. The investigation is separated into 2 groups: in the Live Lab and in the company. The Live Lab occupies a middle position between laboratory studies and field studies in company. The environment in the Live Lab is simulated as a real environment in a company, but more simple, convenient and controllable. The finding from laboratory studies are developed and evaluated in more realistic contxts, whichare possible to be a part of specific field studies e.g. Case studies are evaluated (Benjamin Walter , Albert Albers, Fabian Haupt , Nikola Bursac, 2016). Therefore, Live Lab is usually used for the experiment that requires a real and controllable environment. An investigation in the company requires much effort and time. However, the result of this investigation is more reliable and trustworthy than the result from the Live Lab.

4.3.1 An investigation of the heuristic decision in the Live Lab

The IPEK-Institute for Product Development has 3 potential and effective Live Labs, which are IP (Integrated Product Development), PROVIL (Product Development in a Virtual Idea Laboratory), and AIL (Agile Innovation Lab). These Live Labs have a combination of lectures, exercises and the development project from the company partner. Students have a chance to develop innovative products under real boundary conditions and validate them in the virtual and physical function prototype. Moreover, students have more knowledge about methodologies and processes to develop the product. However, environments, structures, and processes in each Live Lab are different.

IP project is one of the biggest projects in IPEK that is conducted for more than 20 years (Albers, Bursac, Jonas Heimicke, Benjamin Walter & Nicolas Reiß, 2018). This project provides students with many skills such as creating new ideas, selecting product profiles (Albers, Heimicke, Walter et al., 2018) and identifying customer requirements for integrated product development by lectures and workshops in a systematic procedure. Product profile is a model including a number of benefits from provider, customer, and user benefits, which is accessible for validation and explicitly specifies the solution space for the design of product generation. An example of product profile scheme is shown in Figure 4.1.

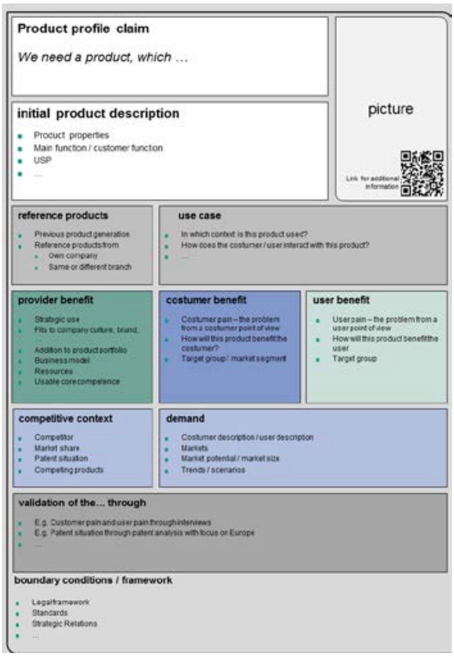


Figure 4.1: Product profile scheme (Albers, Heimicke, Walter et al., 2018)

Students have a chance to study many strategies and methods during the product development such as SCRUM, PERSONA, and SCENARIO. The methods and processes in the IP project have been developed over the year and have been proven successful in many applications. Moreover, the environment in this project is organized to support activities in this project. Two rooms are exclusively made available to the students, which are equipped with seven teams. Each team has 6 workstations and PCs as well as workshop materials.

For the PROVIL project, products are developed under a virtual laboratory with an innovation platform for telecommunication. Students in this Live Lab can develop the product even though they are not in the same place and at the same time. They generate product ideas and translate them into initial product concepts using the innovation platform in each phase. They develop the respective deliverables such as customer profiles, product profiles, product ideas and concepts interactively in teams. In each phase, a pre-evaluation of the deliverables by the students takes place. The project partner also has the opportunity on the platform to give the students feedback on their work status in the sense of early validation. In addition, at the end of each phase, the project partner selects the most promising profiles, ideas, and concepts in the milestone meeting, which are then followed up by the students in the following phase (Albers, Bursac, Walter, Hahn & Schröder, 2016). However, the students do not carry out the selection and adaptation of the methods. Methods are usually determined in all phases during the process.

AIL project is developed to amplify the co-creation approach and consequently expanding the professional skills from IP to gain research competences. The number of participants is; therefore, lower than other Live Labs. The participants (4-5 students) are grouped into one team. They are exploring and developing applied methods. All new findings from the real implementation of methods are analyzed and recorded in the thesis forms that are required for all students in this project. Students in this project; therefore, have high skills of expertise, methodology, society, creativity, and elaboration (Albers, Bursac et al., 2018).

The main objective of experiments inall Live Labs is to investigate an appearance of heuristic decisions in product development and understand their characteristics. However, decisions are made in many activities and from different roles in product development. The investigation was then separated into 2 groups with different main focus and environment. The first group aims to investigate decision making with master students in IP project. Decision making from students in this lab represents the decision making from development team with different roles within each phase. The second group aims to investigate decision making with the staff from company partner in PROVIL and AIL projects. Decisions from these staff showed decisions at the end of each phase, which were more significant than the previous group because these results will be applied in the next phase of product development. Details of each investigation will be explained in the following step.

4.3.1.1 An investigation of the heuristic decision in IP project

An objective in this experiment (Tanaiutchawoot, N., Rapp, S., Bursac, N., & Albers, A., 2018) is to investigate an appearance of heuristic decisions from different roles of decision makers and different activities in product development. This investigation was performed with the IP project 2017 that aims to develop a new product for the automotive industry. The project is divided into 5 phases, which are analysis phase, identifying potential phase, conception phase, specification phase, and realization phase. Figure 4.2 shows 5 phases in IP project.

Figure 4.2: Five phases of product development in IP project (Albers, Bursac et al., 2018)

At the end of each phase, the company partner will participate in the presentation and takes responsibility to provide information and suggestion, and selected a solution.

- The ***analysis phase*** focuses on problem analysis and collecting information.
- The ***identifying potential phase*** aims to investigate the desired product profile based on customer requirements, provider requirements, etc. One product profile, in the end, is selected from each group at the end of the phase.
- The ***conception phase*** is the phase to find several solutions to develop the selected product profile. Simple prototypes are created to simulate and confirm the conceptual idea and solution.

- The ***specification phase*** concentrates on implementing more ideas, techniques, and solutions with the final concept from the company partner. The prototypes in this phase are more realistic.
- The ***realization phase*** is the last phase that focuses on marketing and product launching.

42 students were separated into 7 groups; each group consists of 6 positions that are assigned to all members. These 6 positions are

1) Method Engineer: takes responsibility for the tools and methods that are appropriate in different activities in product development.
2) Validation Engineer: responds to the model and structure validation.
3) System Engineer: works on the whole structure of product development such as the reference product.
4) Marketing and Sales Engineer: focus on customer requirements, competitors, and business model.
5) Construction or Design Engineer: involves the whole calculation of a product's structure.
6) Team Speaker or Team Manager: focuses on managing and cooperating within a team as well as the communication with the external source.

Participants in this investigation were only 7 students from 7 different groups and different roles within their group. Seven participants were interviewed and reported decisions in their groups. Decisions from each role were represented by one student; only the System Engineer position that was represented by 2 students as shown in Table 4.6.

Table 4.6: Roles of participants in each group to participate in the experiment

Role	**Group No.**						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Method Engineer	O						
Validation Engineer		O					
System Engineer			O				O
Marketing and Sales Engineer				O			
Construction or Design Engineer					O		
Team Speaker or Team manager						O	

This structure can provide a variety of decisions from different environments and perspectives under different roles. Each participant is able to present the decisions in the group and in their specific roles. For example, the Sales Engineer explained the decision process to find the target customer.

An overview of processes in this experiment is shown in Figure 4.3.

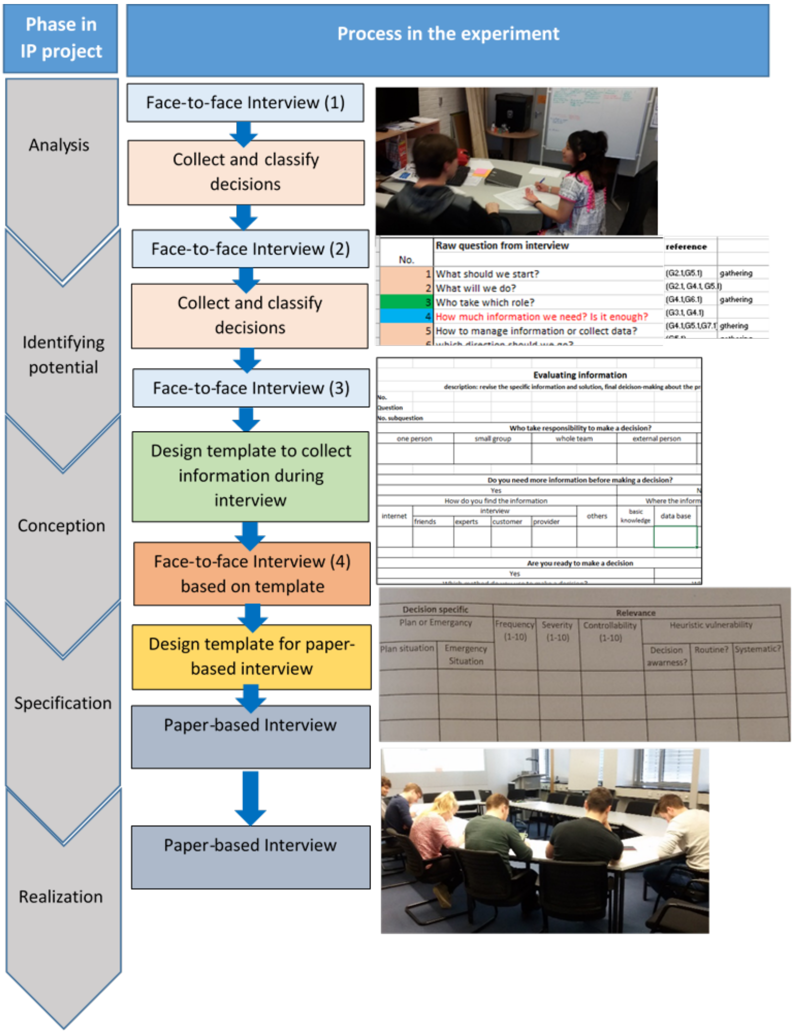


Figure 4.3: An overview of processes in the experiment

At the beginning of this investigation, 7 students as described above were interviewed individually for 30 minutes by face-to-face interviews. The students explained the group's daily activities, especially in decision making. All information in the interview was recorded with a voice recorder and noted on paper. These interviews helped the researcher to notice unaware decision making during the product development process from the participants. For example, the participants could not give information about decision making and did not notice the decision in the activity. The example is "we did not have a meeting this morning because everyone was late and had to go to the workshop, so we did not make a lot of decisions today". They did not recognize that this situation entails 2 decisions, which are the decision to omit the meeting and the decision to go to the workshop. Therefore, the interview in the beginning stage aims to get information from the participants to explain the situations and general activities. After 3 times of face-to-face interview, all decisions from 7 groups were collected, interpreted, summarized and categorized in groups.

Results from the first two phases show that some decisions in the results were similar in all groups and some were specific in each group related to target, especially in the potential finding phase. Regarding to the objective of IP workshop that aims to develop a new product from different ideas, the direction of product development is then different in each group. For example, the first group focused on developing car's door. The second group focused on developing car's battery. Therefore, some decisions were specific for each group. The information from these interviews was not only about decision making, but also the effective factors in the product development process, such as general problems in teamwork and personal characters of team members that lead to different patterns of organization.

The fourth face-to-face interview was repeated again in the conception phase to collect more concreted data during the product development process. Moreover, the researcher investigated the way the team worked during the phase to organize their general workflow in their teams such as rules, meeting periods, personal schedules, and the way they organized the details in the project such as scrum board, and small experiments as shown in Figure 4.4. This investigation helps the researcher to understand situations and decisions that each team explained in the interview. Different situation and environment in each team can lead decision makers to make different decisions.

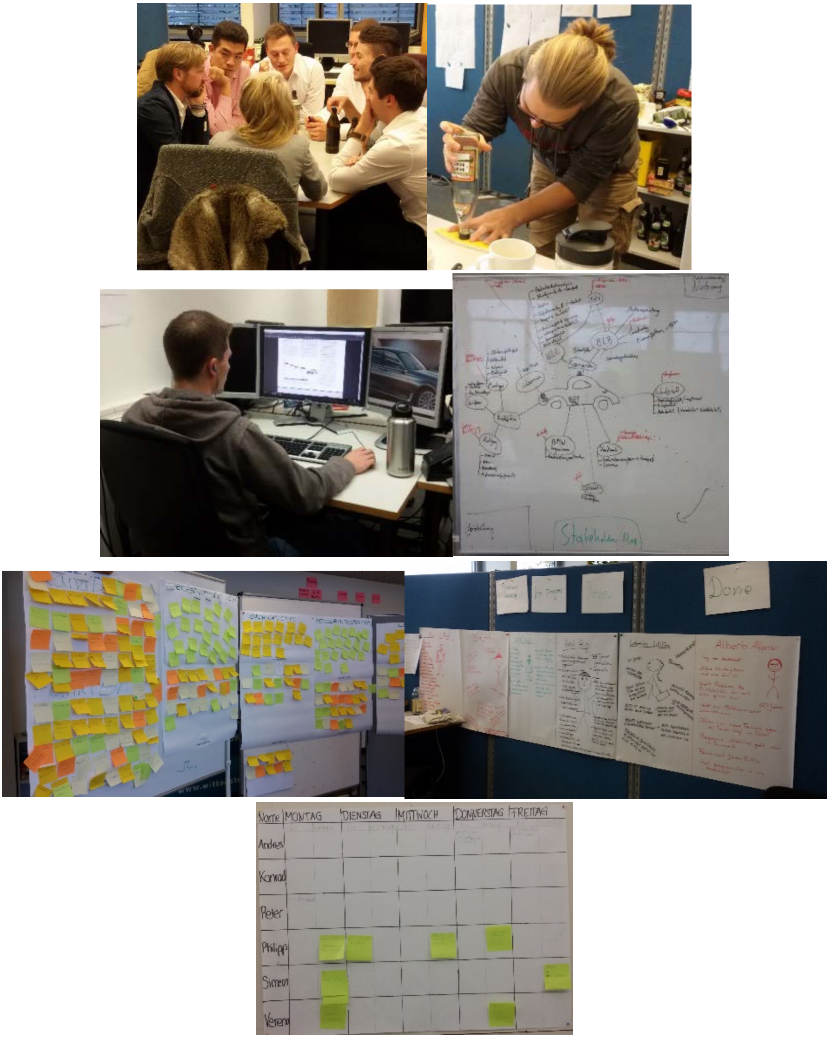


Figure 4.4: Impressions of the product development process in the IP project

After collecting decisions from a face-to-face interview from 7 participants, these decisions were summarized in a list and analyzed to define heuristic decisions. Decision awareness, routine decision, and systematic decision are criteria that are used to evaluate a chance of appearance of heuristic decisions. The heuristic decision usually happens when the decision maker is unaware or acting unsystematically. When the decision occurs in routine; the decision maker has background information and experience about the situation. The chance to make a heuristic decision, therefore, will be lower than in an occasional situation.

Another part is the intensity of the heuristic decision, which can be described in terms of frequency and impact. If that decision had a high frequency and a high impact on the project, that decision should be more concentrated and analyzed regarding the probability to be a heuristic decision or not.

All decisions from face-to-face interview were then evaluated by 7 students based on these five criteria: decision awareness, routine decision, systematic decision, frequency, and impact using paper-based interview. If some decisions in the questionnaire were not made in their team, those decisions were skipped. If some decisions were not in the list, they could add decisions in the blank space.

Figure 4.5 shows components in the questionnaire that is used in the paper-based interview and scaling for each criterion to evaluate decisions.

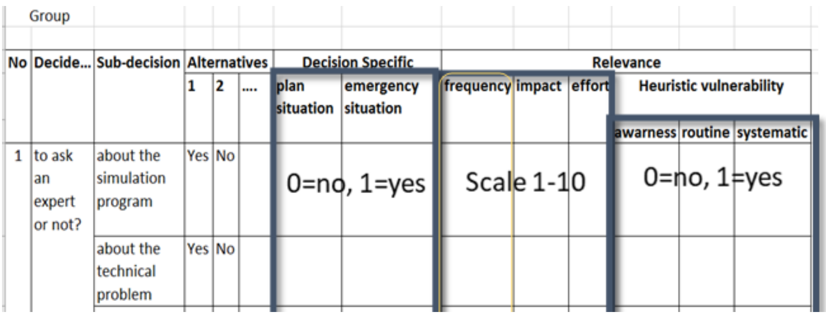


Figure 4.5: Components in the questionnaire

The questionnaire in the paper-based interview consists of the list of questions. Some decisions are in the same direction for all groups; only details are different.

For example, group 1 decided whether they should ask an expert about the simulation program. Groups 2 decided whether they should ask an expert about the technical problem. Details in the same decision were listed in the column of sub-decisions. Examples of alternatives were added in the next column to guide the participants about decisions in the list. Alternatives can be yes-no alternatives such as go further or stop, or open alternatives such as car's components and types of materials. Plan situation and emergency situation were added in the questionnaire to investigate a situation when the decision is made. Results from this part imply an influence of situation in decision making. Five criteria that mentioned in the previous part were then added in the questionnaire. In the part of the decision, the specific and heuristic vulnerability required a yes-no answer. Scaling from 1-10 was used to define the level of frequency, impact, and effort in each decision based on the description in Figure 4.6.

Value	Frequency	Impact	Effort
1	**Very small**: Decision hardly occurs.	**Very small**: The decision does **not affects** to the project	**Very easy**: decision can be made **rapidly.**
2	**Very small**: Decision barely appears	**Very small**: The decision affects **rarely** to the project	**Very easy**: decision can be made in **2-5 minutes**.
3	**Small**: probability decision rarely appears	**Small**: The decision affects **occasionally** to the project	**Easy**: decision can be made but **need basic knowledge**
4	**Small**: Decision occurs occasionally	**Small**: The decision affects **regularity** but not often to the project	**Easy**: decision can be made but need **some knowledge**
5	**Medium**: Decision regularly occurs, but not frequently	**Medium**: The decision affects often to the project	**Medium**: decision can be made but need **a couple of time** and **basic knowledge**
6	**Medium**: decision occurs frequently	**Medium**: The decision **always** affects to the project. The decision have **no impact** to each components	**Medium**: decision can be made but need **a couple of time** and **some knowledge**
7	**High**: Decision occurs **frequently** and on a regular basis	**High**: The decision **always** affects to the project. The decision have **small impact** to each components	**Difficult**: decision can be made but **need a lot of time** and need many details to be considered (very complex)
8	**High**: Decision occurs **regularly** and often	**High**: The decision **always** affects to the project. The decision have **some impact** to each components	**Difficult**: decision can be made but **need a lot of time**, need many details to be considered (very complex) and require **additional knowledge**
9	**Very high**: Decision occurs very **often**	**Very high**: The decision **always** affects to the project. This decision have **high impact** to each components	**Very difficult**: decision **can be made from the external person**
10	**Very high**: Decision **always** occur	**Very high**: The decision **always** affects to the project. This decision have **very high** impact to each components and overall process	**Very difficult**: decision **cannot be made** even try to solve a lot of time and ask a lot of external person (friends, expert,..)

Figure 4.6: The criteria for scoring frequency, impact and effort factor in the questionnaire

Participants took around 1 week to complete the questionnaire. Some decisions that were evaluated differently from other groups were rechecked by interviewing to check the participant's understanding. After rechecking all results from 7 participants, these results were summarized and used in the further step.

During the final phase of the IP project, the 7 participants revaluated their previous answers in the questionnaire. It was possible for them to make a new evaluation based on the decision situation in each phase, which includes the analysis phase, identifying potential phase, conception phase, specification phase, and realization phase.

The evaluation from the 7 participants was averaged and then calculated to find decisions that were possibly made by heuristic decision. The yes-no question was evaluated by scaling with 0 (no) and 1 (yes). 5 factors in the questionnaire, frequency, impact, decision awareness, routine decision, and systematic decision, from 7 participants were averaged and used in the calculation. The formula as showing in Equation 4.1 was formed and calculated in percentage based on the FMEA method, which was called „a heuristic priority number".

$$\frac{F\_avg}{10} \times \frac{I\_avg}{10} \times \left[\frac{(1-A\_avg)+(1-R\_avg)+(1-S\_avg)}{3}\right] \times 100\% \qquad 4.1$$

Where

F_avg= frequency on average from 7 groups
I_avg= Impact on average from 7 groups
A_avg= Decision awareness on average from 7 groups
R_avg= Routine decision on average from 7 groups
S_avg= Systematic decision on average from 7 groups

The highest heuristic priority number from this calculation was 40%; the lowest number was 0%. The decisions that have heuristic priority number over the baseline (≥20%) were listed as heuristic decisions. Therefore, only 22 decisions of 133 decisions were listed in Table 4.7, which will be analysed in details. Decisions in the table are represented by the questions that are required decisions to find the answers

Table 4.7: The top 22 highest heuristic priority number in decisions (from 136 decisions)

Rank	Decisions	Type of decision		Heuristic priority number
		Yes-no	Open	
1	Which type of subsystem could be implemented in new product generation?		X	40%
2	Which main target should be delivered at the end of the phase/sprint?		X	33.18%
3	Which information do we need for the specific function?		X	32.11%
4	Should we try or not use a new method for gathering information?	X		27.08%
5	Should I give opinions or suggestions in the group?	X		26.66%
6	Which process should be used for filtering information to find the conceptual idea?		X	26.54%
7	Whether the information is important for collecting in the database?	X		23.33%
8	Which information do we need for implementing in the program simulation?		X	23.15%
9	Which question should be used to interview customers?		X	22.99%
10	Should we stop the meeting or go further after limitation time?	X		22.51%
11	Which duration of time should we spend on each task when finding technical information such as type, function, and application?		X	22.46%
12	Whether to stop creating ideas to find solutions or to go further?	X		22.17%
13	Do members work independently or in a group when designing criteria and creating the idea?		X	22.02%
14	Should I stop searching for information or go further?	X		21.88%
15	Which sources should be used to find the information (ex. Internet, expert, backup data)?		X	21.63%
16	Whether this information, idea, requirement, and solution are important for the future?	X		21.33%
17	Which information should be consulted with an external person?		X	21.16%

Rank	Decisions	Type of decision		Heuristic priority number
		Yes-no	Open	
18	Which information do we need for the specific subsystem such as design, function, material, etc?		X	21.01%
19	Which main part of the product should be focused on developing in the next generation?		X	20.67%
20	Which criteria should be used for gathering ideas such as advantages for the future, the benefit for the provider, etc?		X	20.15%
21	Which sources should be used to identify criteria such as customer's requirement, provider's requirement, etc?		X	20.10%
22	Should the idea be kept, reduced or discarded?	X		20.00%

These 22 heuristic decisions have different characters such as types of decisions (yes-no or open) and came from different phases, activities, and roles in product development. The result implies that heuristic decisions can be used in both yes-no questions or open questions. In another word, the number of alternatives does not relate to using heuristic decisions to make a decision or not. To develop a better understanding about heuristic decisions in product development, the iPeM-integrated Product Generation Engineering Model was used to classify these decisions based on components in product development. This model is an integrated approach to fill the gap between process management and engineering design as described in the literature review section. The 22 heuristic decisions were then analyzed based on the operating system that consists of a phase model, resources, problem-solving activity, basic activities, and product engineering. This process was reviewed by 2 persons who are expert in the iPeM model. The probability of occurrence of the 22 heuristic decisions was then determined and presented in percentages. For example, if all 22 heuristic decisions appeared in the phase of phase modelling, the probability was 100%. On the other hand, if none of 22 heuristic decisions appeared in the phase of phase modelling, the probability was 0%. The result of this analysis is shown in Table 4.8.

Table 4.8: The probabilities of occurrence of 22 heuristic decisions based on the operating system in the iPeM model

Main topics	Sub-categories	Probability of occurrence of heuristic decision
Phase model	Analysis	72.73%
	Identification potential	100%
	Conception	100%
	Specification	86.36%
	Realization	77.27%
Resources	Team	55%
	Expertise	18.18%
	Tools	9.09%
	Financial	0%
	Information	71.43%
Problem-solving activity	S: Situation analysis	77.27%
	P: Problem containment	77.27%
	A: Detection of an alternative solution	54.55%
	L: Selection of solution	63.64%
	T: Analysis of consequences	50%
	E: Deciding and implementing	81.82%
	N: Recapitulation and learning	22.73%
Basic activities	Management projects	31.82%
	Validate and verify	54.55%
	Manage knowledge	68.18%
	Manage changes	19.05%
Product engineering	Detect profiles	68.18%
	Detect ideas	81.82%
	Model principles solution and embodiment	63.64%
	Build up prototype	45.45%
	Produce	27.27%
	Market launch	45.45%
	Analyze utilization	45.45%
	Analyze decommission	40.91%

The result in Table 4.8 shows that heuristic decisions usually appear because of information and team. Based on the interview, information to support decision making is insufficient, and some information needs time to be found. Members in the team is another point that can cause heuristic decision. Each person has personal thinking and characters, which influences team's solution in different directions. Different knowledge, experience, and roles also relevant to how the decision is made.

For example, the student who was the Method Engineer tried to apply a method in the decision making. Other students sometimes ignore the method and make a rapid decision using their knowledge and experience. This investigation is similar to the basic theory of heuristic decisions. In the product development process, heuristic decisions can appear in the whole processes and activities, especially manage knowledge activities, detect profiles, detect ideas, and model principles solution and embodiment. These activities usually appear in the front-end phase (Steven A. Murphy and Vinod Kumar, 1997) that is uncertain and has limited information. On the other hand, these activities are important to define the project in different directions.

The result from this experiment; however, presents only the decisions that seem to be the heuristic decision based on a heuristic priority number. Types of heuristics and biases, and the effect results (good-bad result) from heuristics and biases to decisions are not identified.

4.3.1.2 An investigation of the heuristic decision in PROVIL and the AIL project

The investigation of the heuristic decisions in the PROVIL and AIL project is different from the investigation in the IP project. Results from this investigation came from observation and experiment. Moreover, participants in the investigation were the decision makers from the company partner who took responsibility to provide a suggestion and make a decision at the end of each phase.

The first observation was performed at the end of the detect profile phase in the PROVIL project. This phase is the first phase in product development and has high chance that heuristic decisions will be appeared. Within this project, students were separated to 7 teams, and each team consisted of 5-6 students. Their assignment was to develop car’s interia for one company. After doing design methods to create product profile, each team made a presentation to 7 Participants from the company partner to select the best product profile from each team. Then these product profiles will be developed in the further steps. Processes to select product profile are shown in Figure 4.7.

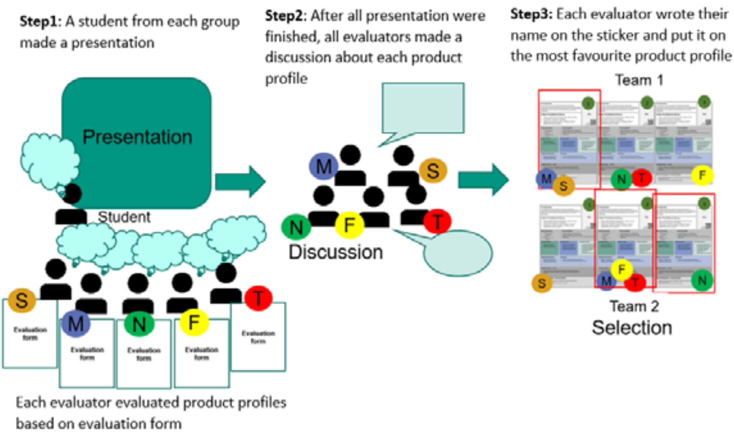


Figure 4.7 Processes to select product profiles in PROVIL project

At the beginning of evaluation, participants made an evaluation individually for each product profile when the students made a presentation using an evaluation form regarding 6 criteria. These criteria are chance of market success, customer pain, and frequency of use, reference product, and technical feasibility. Scaling for each criterion starts from 1 to 3. Description of score for each criterion is shown in Figure 4.8.

Criteria	Description	1	2	3
Chance of market success	How big is the competition?	Relevant competitors can **generally appear** in businesses such as cell phones, computers, etc	A relevant competitor can occur in the **vehicle industry** such as motorcycles and trucks	Relevant competitor can only appear in the **automotive industry (only car)**
Customer pain (size of customer)	How many problems / pain points are solved by the product to be developed?	Problems of a **specific group** (e.g. man / woman, older / teenager, group / individual) **Area**: vehicle	Problems of a **specific group** (e.g. man / woman, older / teenager, group / individual) **Area**: vehicle and beyond. **or** Problems of a large group (e.g. man / woman, all age groups) **Area**: vehicle	Problems of a **large group** (e.g. man / woman, all age groups) **Area**: vehicle and beyond.
Frequency of use	How often does the use case occur?	< **1 time** per week	**2-6 times** per week	**>6 times** per week
Reference product	Which area does the reference product come from, which is probably the most similar to the product to be developed?	Reference product from **other industry**	Reference product from the **same industry**	Reference product from the company
Technical feasibility	Technical resources of the organization (e.g. experts, know-how, new hardware, software) and their applicability to the problem	**Need** supportation from **outside**	**Have some resources**, but take time and effort to implement	**Have all** the necessary resources and can use them quickly

Figure 4.8: Description of each score for each criterion

An example of the evaluation and final selection from 7 participants to team 1 and team 2 is shown in Figure 4.9.

Teams	Product profile no.	Participant	Chance of market success	Customer pain	Frequency of use	Reference product	Technical feasibility	Total	Final selection
Team 1	Profil 1.1	A	2	2	2	1	3	10	
	Profil 1.2		2	1	1	2	2	8	
	Profil 1.1	B	2	1	2	3	1	9	
	Profil 1.2		2	1	1	1	2	7	
	Profil 1.1	C	3	2	2	1	2	10	
	Profil 1.2		2	1	1	1	1	6	
	Profil 1.1	D	2	3	3	3	3	14	
	Profil 1.2		2	2	2	3	2	11	
	Profil 1.1	E	2	1	2	1	1	7	
	Profil 1.2		2	1	1	1	1	6	
	Profil 1.1	F	2	2	2	1	2	9	
	Profil 1.2		2	2	1	1	2	8	
	Profil 1.1	G	2	2	2	1	2	9	
	Profil 1.2		1	1	1	1	2	6	
Team 2	Profil 2.1	A	3	2	2	1	2	10	
	Profil 2.2		2	2	2	1	2	9	
	Profil 2.1	B	2	1	2	1	3	9	
	Profil 2.2		1	1	1	1	2	6	
	Profil 2.1	C	3	2	3	1	2	11	
	Profil 2.2		3	1	1	2	2	9	
	Profil 2.1	D	3	3	3	3	3	15	
	Profil 2.2		3	2	2	3	3	13	
	Profil 2.1	E	3	2	3	1	2	11	
	Profil 2.2		2	1	1	1	2	7	
	Profil 2.1	F	3	2	1	1	1	8	
	Profil 2.2		2	1	2	1	3	9	
	Profil 2.1	G	3	1	2	1	1	8	
	Profil 2.2		1	1	1	1	2	6	

Figure 4.9: An example of evaluation and final selection in the detect profile phase

A number that have red colour in the “Total” column in Figure 4.9 are the highest score regarding the score for each product in each group. Participants should select the product profile that has the highest score. However, most of them selected other product profile that is shown with green colour in the final column. After analysing results of evaluation from 7 participants with 7 teams, 71.43% of the final solution did not come from the highest score in the evaluation with criteria. The participants made a final decision without relying on the result from the evaluation. The participants selected the product profile that even had a low score in every criteria in the evaluation process. The participants decided to ignore the suggestion from the method (evaluation form) and selected the final product profile based on their intuitive. One possible reason can be the criteria and the descriptions in each criterion and score cannot concrete and cover the participant’s objective. However, finding suitable criteria in the evaluation and defining each scale value and criterion is difficult and complex. Moreover, number of criteria should not be high to reduce time consumption and effort. Therefore, the decision makers decided to select the solution using the heuristic decision. The result from this experiment, therefore, implies that a heuristic decision is sometimes more acceptable than a systematic decision.

The similar character of decision making in this experiment also happened in the AIL project using observation method. One group of students in the AIL project proposed 3 options of product profile and results of evaluation using benefits analysis. Six criteria were used in the analysis, which are practicability, significant of overall product, market size, known-how from the company, creativity degree, and possible application. The evaluation was done by students in the team during the creativity workshop. Each product profile was evaluated based on information from the research and expert in the company. Results of this analysis were shown in Figure 4.10.

After presenting these 3 product profile including concept idea and the evaluation, 4 experts from the company made a discussion and selected the third product profile or product profile C in Figure 4.10 that does not get the highest score in the evaluation.

Criteria	Weight	Product profile		
		A	B	C
Praticability	2	30	36	44
Significant of overall product	1	15	24	17
Market size	2	50	20	30
Know-how from the company	1	24	17	16
Creativity degree	1	16	22	12
Possible application	1.5	34.5	30	30
Total		169.5	149	149

Final Selection

Figure 4.10: Three options of product profile with the benefit analysis and final selection

One interesting point based on the observation during group discussion from company, product profile number C was selected based on a suggestion from one participant. At the beginning of discussion, 4 participants had different ideas for the final selection. After one participant expressed his opinion regarding his idea of selection, others agreed with his suggestion and selected the product profile C without following the suggestion from the evaluation. This result also shows an influence of heuristic decisions and biases in decision making. People seems to use their knowledge and experience to select the solution even it is against some information (the result of evaluation).

Another group of students in the AIL project also encountered the same situation but at the end of the idea detection phase and technical solution phase. Students proposed 3 solutions with the evaluation using colour scale. The example from the evaluation for the technical solution is shown in Figure 4.11.

Figure 4.11: The evaluation of technical solutions for the product

An evaluation was changed from qualitative (scaling or score) to be quantitative (colour: green, yellow, red) to decrease complexity of evaluation and indefinable score. However, the decision makers from the company did not make a decision relied on this evaluation. Most decisions usually based on experience and knowledge from personal thinking. The participants explained that even alternatives were in the same group colour, but their quality is not actually similar. Some alternatives can also be green and yellow, which is difficult to make a decision. Therefore, evaluation in quality (good/bad, worse/better) by feeling is sometimes easier than quantity (values, group) by methods.

Regarding one experiment in PROVIL project and two observations in AIL project, Table 4.9 summarized 3 heuristic decisions that showed a high power in the decision making when selecting the product profile, idea solution, and technical solution.

Table 4.9: Heuristic decisions in the PROVIL and AIL projects

No.	Decisions	Type of decisions	
		Yes-no	Open
1	Which product profile should be selected for the new product?		X
2	Which concept idea should be developed and implemented in the new product?		X
3	Which technical solution should be implemented in the new product?		X

These decisions are additional decisions from the list in the experiment with IP project. Actually these decisions appeared in the experiment in IP project, but students usually made decisions based on results from design methods and suggestion from experts. This is different from decisions from experiments in PROVIL and AIL project, which decisions were made by the experts from company. Results from these 3 Live Labs show that heuristic decisions and biases appear in all activities of product development and all roles of decisions makers.

4.3.2 An investigation of heuristic decisions during product development in company environment

This investigation aims to investigate heuristic decisions of product development in the company that are made under uncontrollable environment, which is different from the environment in the Live Lab. Based on the policy, structures and resources, decisions have sometimes more details and complicated than decisions in Live Lab. All decision makers also take their responsibility regarding their roles, knowledge and experience to find solutions. Processing time and procedures are also strict. Decision making usually comes from many steps and roles of decision makers to find the final solution.

In an uncontrollable environment, an investigation in a company is then limited. The observation and interview methods were, therefore, selected for the action research. The observer took part in the development team of the company. The observer had to develop the product and observed the decision behavior during product development from himself and members in his team.

This investigation was in one of the leading automotive companies. The observer took part in a small project that aims to develop a special testing scenario and catalogue for future ADAS testing including optimizing and development of specific functions for the Chinese market (Zhao, 2019)[1]. This process of product development was mainly in the model principles solution and embodiment phase. However, some decisions were made in the profile detection phase and an idea detection phase. This investigation had been done for 6 months, which was the total period to achieve one part of product development. There were 4 decision makers from different roles (1 manager, 1 expert, and 2 engineers) who took responsibility to make decisions in this project. The template to collect decisions (in

Figure 4.12) was designed based on an idea from the IP project.

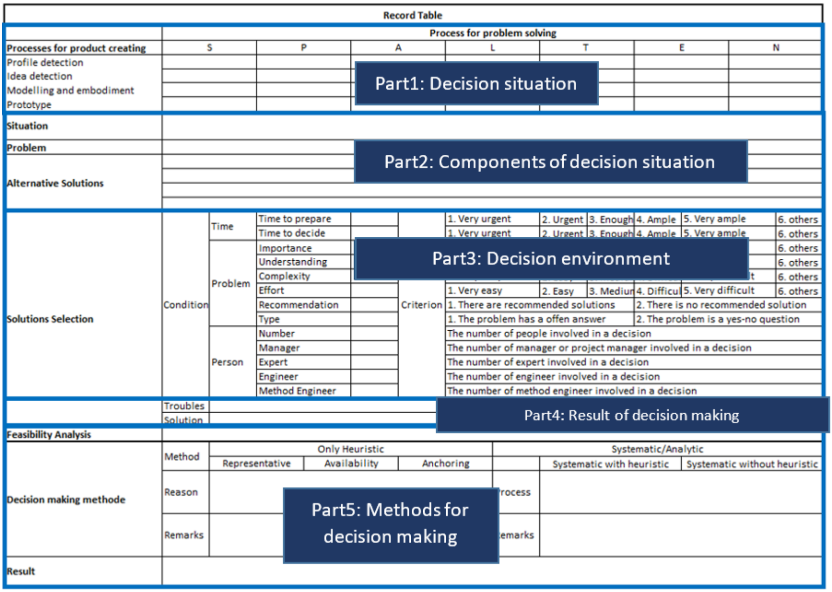


Figure 4.12: The template to collect decision making in the product development project from one automotive company

Method to define systematic or heuristic decisions in this observation were different from the method in the experiment in IP project. Factors to calculate a heuristic priority number such as frequency cannot be used in this case because most decisions concentrated on technical decisions that were specific in situations. They

[1] Co-supervisor of Master thesis

are not the routine decisions as shown in the IP project. In this investigation, types of the decision were, therefore, identified by the observer's consideration that is similar to the method in PROVIL and AIL projects but more systematic. The observer interviewed the decision maker to get more information in case that the method to make a decision was vague. Each heuristic decision was also identified in 3 types, which are the representativeness heuristic, the availability heuristic, and the anchoring and adjustment heuristic. From

Figure 4.12, the template was separated into 5 parts.

Part 1: Decision situation aims to classify decisions based on product development activity and problem-solving activity from the iPeM model.

Part 2: Components of decision situation was used to clarify the situation of decision, problem, and alternative solutions.

Part 3: Decision environment consists of different environments that decisions were made such as time, complexity, and participants. Each condition was assigned with the score defined in the template. For example, if the preparation time for that decision is short or urgent, the value "1" is assigned in the space of "time to prepare". Results from this part can refer to influenced factors in the heuristic decision.

Part 4: Result of decision making recorded the problem and solution if the decision has an error or mistake.

Part 5: Methods for decision making was used to recorded types of decisions and explanations of the decision situations, and also the final result of the decision.

After 6 months of investigation in this project, 92 decisions were collected in a question form and only 38 (41%) decisions were made by heuristic decisions. From 38 heuristic decisions, the availability heuristic was mostly used in this project (84%). 11% of the heuristic decision was the representativeness heuristic, and the rest was the anchoring and adjustment heuristic. However, there were some decisions that were similar but appeared in different situations. After modifying and grouping decisions, 34 heuristic decisions that were in the question form were listed in

Table 4.10.

Table 4.10: Heuristic decisions in the project from one automotive company

No.	Decisions	Type of decision		Type of heuristic decision
		Yes-no	Open	
1	Is there a test catalog for the scenario of specific traffic in China ?	X		Availability
2	What are the usage and usage scenarios of data?		X	Availability
3	What should be developed?		X	Representativeness
4	What are the usage and usage scenarios of data feasible?		X	Availability
5	Which component should we develop?		X	Availability
6	What's the current situation?		X	Availability
7	What's the goal in general?		X	Availability
8	What's the detail in the specific traffic in China?		X	Availability
9	What are the characteristics feasible?		X	Availability
10	How can the goal be approached to select a solution?		X	Availability
11	Is the approach to achieve the goal feasibly?	X		Availability
12	What are the alternative solutions based on the number and location of standardized data interfaces?		X	Availability
13	How much data will occur in the future?		X	Anchoring
14	In which possible time periods should the data be collected?		X	Availability
15	What are the possible requirements for driving the behavior of eco vehicle when collecting data,		X	Availability

No.	Decisions	Type of decision		Type of heuristic decision
		Yes-no	Open	
	especially the requirements of driving lanes?			
16	What are the alternative solutions to the methods to approach the parameters?		X	Availability
17	What kind of possible road can be used to test the system?		X	Availability
18	How can the data be determined		X	Availability
19	Which data will be collected to determine the city's environment?		X	Representativeness
20	Which type of road should be used to test the performance of the product?		X	Availability
21	Which data should be collected in each time period?		X	Availability
22	How can the data be structured?		X	Representativeness
23	Which route should be used to test the performance of the product?		X	Representativeness
24	Is it feasible to use Lidar (LUX) to collect data on the real road?	X		Availability
25	Is it feasible to test in Beijing?	X		Availability
26	Is the selected solution of decision about road types and the route feasible?	X		Availability
27	Is the selected solution of decision about collecting periods feasible?	X		Availability
28	Are the selected requirements to standardize driving behavior feasible?	X		Availability
29	Will the quality of data be reached?	X		Anchoring
30	Is the selected place good to store data?	X		Availability
31	Is the number and location of standardized data interfaces right?	X		Availability

No.	Decisions	Type of decision		Type of heuristic decision
		Yes-no	Open	
32	Is the candidates, we determined for the Evaluation matrix, feasible?	X		Availability
33	Is the structure suitable for future work or not?	X		Availability
34	Is the testing plan feasible?	X		Availability

More than 50 % of heuristic decisions occurred in the situation analysis (S) and analysis of consequences (T) in a problem-solving activity. Heuristic decisions in the deciding and implementing (E), and recapitulation and learning (N) were not investigated in this project because the decision makers had no responsibility to make any decisions in these 2 activities and could not participate in these situations.. The decisions in these 2 activities were taken by a supplier. Heuristic decisions in this project were observed only in the detect profiles, detect ideas, and model principle solution and embodiment activity of product development because the project was relevant to only these 3 activities. Therefore, this investigation was more specific in these 3 activities than other investigations in Live Labs. Relevant factors that can lead decision makers to rely on heuristic decisions were the time of preparation to make a decision, time to make a decision, an importance level of decision, a level of understandable on the decision from a decision maker, a complexity level of decision and required the effort of the decision maker. Some of these factors were similar to the factors as described in the literature. Decision makers' decisions usually rely on heuristic decisions in an urgent situation. Heuristic decisions were used to save effort in decision making. However, decision makers sometimes use heuristic decisions in the high complexity cases of the decision to go to the further step instead of ignoring the decision. Therefore, heuristic decisions are not only used in the low complexity cases of the decision, but they are also used in the situation that systematic decisions cannot be used to find the solution.

4.3.3 Conclusion from the investigation in the Live Lab and in the company

Based on the knowledge from literature and results from experiments in 3 Live Labs and one company, solutions were selected by both systematic and heuristic decisions. They were used in different levels based on the complexity of decisions, time to prepare information and make a decision, impact of the decision to the project, frequency, experience of decision makers regarding that decision, required effort from the decision makers, and reliability of the result from a systematic decision.

Fifty-nine heuristic decisions from the investigation in 3 Live Labs (25 decisions in Table 4.7and Table 4.9) and 1 company (34 decisions in

Table 4.10) were summarized and classified into 2 groups: yes-no alternatives and multiple alternatives. All heuristic decisions were then mapped in the iPeM model to find a percentage of appearance of heuristic decisions in product development from these 59 decisions based on product-development activities and problem-solving activities. Figure 4.13 shows processes to summarize all heuristic decisions from the investigation and map them into iPeM model.

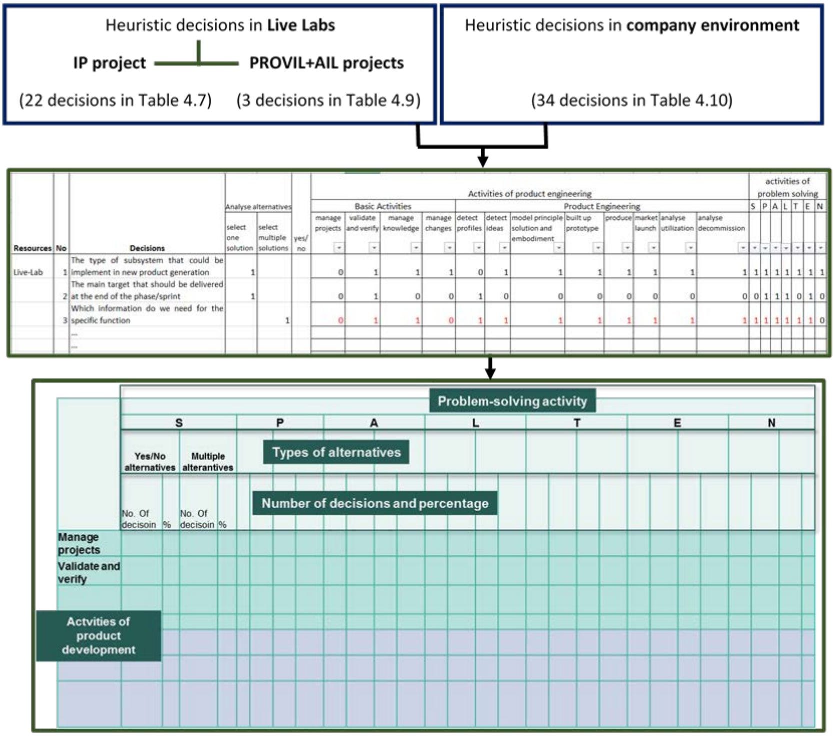


Figure 4.13: Processes to summarize and classify 59 heuristic decisions from the investigation based on the iPeM model

Figure 4.14 shows a number and percentage of heuristic decisions in each product-development activity and problem-solving activity from the iPeM model based on 59 heuristic decisions from the investigations.

Actvities of product development	S				P				A			
	Yes/No		Multiple		Yes/No		Multiple		Yes/No		Multiple	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Manage projects	3	5,1	4	6,8	3	5,1	3	5,1	1	1,7	1	1,7
Validate and verify	3	5,1	6	10	3	5,1	8	14	1	1,7	7	12
Manage knowledge	4	6,8	7	12	4	6,8	7	12	2	3,4	6	10
Manage changes	2	3,4	2	3,4	2	3,4	2	3,4	1	1,7	2	3,4
Detect profiles	6	10	5	8,5	5	8,5	6	10	2	3,4	6	10
Detect ideas	6	10	9	15	6	10	9	15	3	5,1	7	12
Model principle solution and embodiment	4	6,8	7	12	4	6,8	6	10	1	1,7	11	19
Built up prototype	3	5,1	4	6,8	3	5,1	3	5,1	1	1,7	3	5,1
Produce	2	3,4	4	6,8	2	3,4	4	6,8	1	1,7	4	6,8
Market launch	3	5,1	5	8,5	3	5,1	5	8,5	2	3,4	3	5,1
Analyse utilization	2	3,4	5	8,5	2	3,4	5	8,5	1	1,7	5	8,5
Analyse decommission	2	3,4	5	8,5	2	3,4	4	6,8	1	1,7	4	6,8

Actvities of product development	L				T				E				N			
	Yes/No		Multiple		Yes/No		Multiple		Yes/No		Multiple		Yes/No		Multiple	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%		%	No.	%
Manage projects	1	1,7	1	1,7	2	3,4	1	1,7	3	5,1	3	5,1	1	1,7	1	1,7
Validate and verify	1	1,7	8	14	2	3,4	4	6,8	3	5,1	7	12	0	0	1	1,7
Manage knowledge	4	6,8	7	12	5	8,5	5	8,5	6	10	7	12	3	5,1	2	3,4
Manage changes	1	1,7	2	3,4	1	1,7	2	3,4	2	3,4	2	3,4	0	0	1	1,7
Detect profiles	4	6,8	8	14	5	8,5	3	5,1	9	15	6	10	3	5,1	0	0
Detect ideas	5	8,5	8	14	8	14	5	8,5	8	14	6	10	3	5,1	2	3,4
Model principle solution and embodiment	4	6,8	12	20	15	25	4	6,8	6	10	5	8,5	3	5,1	1	1,7
Built up prototype	3	5,1	4	6,8	3	5,1	3	5,1	5	8,5	4	6,8	3	5,1	1	1,7
Produce	1	1,7	4	6,8	1	1,7	4	6,8	2	3,4	4	6,8	2	3,4	1	1,7
Market launch	3	5,1	4	6,8	3	5,1	4	6,8	5	8,5	4	6,8	3	5,1	2	3,4
Analyse utilization	3	5,1	5	8,5	3	5,1	4	6,8	4	6,8	4	6,8	3	5,1	2	3,4
Analyse decommission	3	5,1	4	6,8	3	5,1	4	6,8	4	6,8	4	6,8	3	5,1	2	3,4

Figure 4.14: Number of heuristic decisions in each product-development activity and problem-solving activity from the iPeM model regarding 59 heuristic decisions from the investigation in Live Labs and company

In this research, the researcher concentrates on the heuristic decisions and biases with multiple alternatives in the selection of solution (L) in problem-solving activity within the detect profile activity and detect idea activity in the product-development activity. Decisions in this phase are important because results from this period are the starting point to indicate the direction of product development. Moreover, decisions in these activities in product development are usually made in limited information and uncertain environments, which require effective techniques to improve decision making. The heuristic decisions in these activities are listed in Table 4.11.

Table 4.11: Twelve heuristic decisions with multiple alternatives in the selection of solution in the problem-solving activity that appeared in the detect profile activity and the detect idea activity in product development activity.

No.	Decisions	Product development activities
1	Which main target should be delivered at the end of the phase/sprint?	Detect profile
2	Which information do we need for the specific function?	Detect profile and detect idea
3	Which information do we need for implementing in the program simulation?	Detect profile
4	Which questions should be used to interview customers?	Detect profile and detect idea
5	Which information do we need for the specific subsystem such as design, function, material, etc?	Detect profile and detect idea
6	Which main part of the product should be focused on developing in the next generation?	Detect profile
7	Should we keep, reduce or discard the idea?	Detect profile and detect idea
8	Which product profile should be selected for the new product?	Detect profile
9	Which type of subsystem could be implemented in new product generation?	Detect idea
10	Which process should be used for filtering information to find the conceptual idea?	Detect idea
11	Which information do we need for implementing in the program simulation?	Detect idea
12	Which technical solution should be implemented in the new product?	Detect idea

Decisions in Table 4.11 represent heuristic decisions in activities of product development. These decisions are then analysed and investigate an appearance and influence of cognitive biases in the further step.

4.4 Supporting methods for solution selection and decision making

After investigating many decisions from Live Labs and company environment, heuristic decisions appeared in decision making even using a design method to support decision making such as the experiment in PROVIL project. This observation hints the researcher to also investigate heuristic decisions when using design methods to support decisions making.

In product development, there are many design methods that are used to support decision making in many activities starting from analyzing the situation of the decision to record and review the final selection as described in the literature. This research, however, focuses on the design methods for solution selection and decision making. The design methods are collected based on the literature and information from the InnoFox that was developed by IPEK to provide a specific product development method (Albers, A., Reiß, N., Bursac, N., Walter, B., & Gladysz, B., 2015). Ninety methods from different sources are then collected including name and description. After analysing all methods, some of them have a similar concept idea and process for decision making. Some methods evaluate alternatives based on criteria or minimum baseline such as Multicriteria Decision Analysis (MCDA). Some methods make an evaluation by comparing between alternatives such pairwise comparison method. And some methods require many data and compute information using mathematic calculation and specific algorithm such as fuzzy logy. These 3 different concept ideas of evaluation are required different level of heuristic and systematic decisions. Instead of analyzing heuristic decisions in all methods, heuristic decisions based on these concept ideas were then considered. All 90 methods are classified into 3 groups, which are comparing alternatives regarding criteria, comparing between alternatives, and no comparison.

- Group 1: Comparing alternatives regarding criteria; methods in this group require criteria to evaluate alternatives. The alternatives can be classified in terms of pass/fail, good/bad, or by ranking. However, the decision usually depends on the proposed criteria.
- Group 2: Comparing between alternatives; methods in this group aim to compare alternatives to find the ranking solution. Criteria can be implicit or explicit depending on the situation and information in decision making.
- Group 3: No comparison; methods in the last group are usually based on data analysis and models.

Methods in each group are presented in Table 4.12. The description of each method shows in Appendix B

Table 4.12: Methods to support decision making by comparing alternatives to criteria

Methods to support decision making by comparing alternatives to criteria	**Methods to support decision making by comparing alternatives**	**Methods to support decision making without comparing alternatives (analyze data)**	
ABC-Analysis	AHP (analytic hierarchy process)	AD (axiomatic design)	Kanban
Benefit analysis	ANP (analytical network process)	Bayesian analysis	Knowledge Cafe
Cluster analyzis	Conjoint Analyse	Bayesian Belief Network (BBN)	Markov method
Concept selection (Konzeptauswahlanalyse nach Pugh) /Pugh's evaluation	Decision node/decision map	Benchmark	Morphologische Analyse
Conjunction heuristic	Decision tree	Best Practice Sharing	Netzplantechnik
Influence matrix/ Consistent matrix	Pairwise comparison	Black-Box	OPT (options pricing theory)
Decision matrix	Take the best	Brainstorming	Outside-In Technologietransfers
Disjunctive heuristic		Brainwriting Pool	Patentportfolio
Elimination by aspect		BSC	Persona
FDSM (Fuzzy Design structure matrix)		Canonical model	Poke Yoke
Feasibility analysis (Herstellbarkeitsbewertung)		CBR (cased based reasoning)	Project record
FMEA (Failure Mode and Effect Analysis)		Checklist	Process Failure Mode and Effect Analysis (pFMEA)
FQFD (Fuzzy quality function deployment)		Community-Platform	Process capability analysis
FSEM (Fuzzy synthetic evaluation method)		Contact and Channel Approach (C&C2-A)	Quality control chart
Fuzzy C-Means (FCM): Fuzzy clustering means		Database system	Red-Tag-Analyse

Methods to support decision making by comparing alternatives to criteria	**Methods to support decision making by comparing alternatives**	**Methods to support decision making without comparing alternatives (analyze data)**	
House of quality		DEA (Data envelopment analysis)	Reviewing reference projects when designing new project
Kano method		Decision score model	Scenario analysis
MAUT (Multi-Attribute Utility Theory)		Delphi Method	Scenario management
Multidimensional Scaling		Design-to-cost (DTC)	Sensitivity method
MCDM (multi-criteria decision making)		Dynamic problem solving (DPS)	Stimulus word analysis
MODM (Multiple objective decision making)		FAQ Kataloge (frequently asked questions)	Synectics
MADM (Multiple attribute decision)		Fishbone diagram (Ursache-Wirkungs-Diagramm)	SWOT-Analyse
Punktbewertung		Forecasting by analogy (Analogiebildung)	Technical feasibility study
Quality Function Deployment (QFD)		Fuzzy Information Axiom (FIA)	Technology Roadmapping
scoring model and checklist		Fuzzy logic/fuzzy set theory	Trend analysis
SMART (Simple multi-attribute rating technique		Galeriemethode	TRIZ
Tallying		Hypothetical Equivalents and Inequivalents Method (HEIM)	Value stream mapping
TOPSIS (a technique for order preference by similarity to the Ideal Solution)			
Walt Disney Method			

4.5 Possibility of heuristic decisions and biases in product development

Based on the previous studies, heuristic decisions and biases in product development can be analysed from 3 components: 1) Heuristic decisions situations, 2) heuristic decisions and biases, and 3) techniques for decision making. These three components are analysed individually in details and grouped as described in the previous studies. An overview of the connection from these 3 components is shown in Figure 4.15.

Problem-solving activity

Actvities of product development	S				P				A				L			
	Yes/No		Multiple		Yes/No		Multiple		Yes/No		Multiple		Yes/No		Multiple	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Manage projects	3	5,1	4	6,8	3	5,1	3	5,1	1	1,7	1	1,7	1	1,7	1	1,7
Validate and verify	3	5,1	6	10	3	5,1	8	14	1	1,7	7	12	1	1,7	8	14
Manage knowledge	4	6,8	7	12	4	6,8	7	12	2	3,4	6	10	4	6,8	7	12
Manage changes	2	3,4	2	3,4	2	3,4	2	3,4	1	1,7	2	3,4	1	1,7	2	3,4
Detect profiles	6	10	5	8,5	5	8,5	6	10	2	3,4	6	10	4	6,8	8	14
Detect ideas	6	10	9	15	6	10	9	15	3	5,1	7	12	5	8,5	8	14
Model principle solution and embodiment	4	6,8	7	12	4	6,8	6	10	1	1,7	11	19	4	6,8	12	20
Built up prototype	3	5,1	4	6,8	3	5,1	3	5,1	1	1,7	3	5,1	3	5,1	4	6,8
Produce	2	3,4	4	6,8	2	3,4	4	6,8	1	1,7	4	6,8	1	1,7	4	6,8
Market launch	3	5,1	5	8,5	3	5,1	5	8,5	2	3,4	3	5,1	3	5,1	4	6,8
Analyse utilization	2	3,4	5	8,5	2	3,4	5	8,5	1	1,7	5	8,5	3	5,1	5	8,5
Analyse decommission	2	3,4	5	8,5	2	3,4	4	6,8	1	1,7	4	6,8	3	5,1	4	6,8

Actvities of product development	T				E				N			
	Yes/No		Multiple		Yes/No		Multiple		Yes/No		Multiple	
	No.	%	No.	%	No.	%	No.	%		%	No.	%
Manage projects	2	3,4	1	1,7	3	5,1	3	5,1	1	1,7	1	1,7
Validate and verify	2	3,4	4	6,8	3	5,1	7	12	0	0	1	1,7
Manage knowledge	5	8,5	5	8,5	6	10	7	12	3	5,1	2	3,4
Manage changes	1	1,7	2	3,4	2	3,4	2	3,4	0	0	1	1,7
Detect profiles	5	8,5	3	5,1	9	15	6	10	3	5,1	0	0
Detect ideas	8	14	5	8,5	8	14	6	10	3	5,1	2	3,4
Model principle solution and embodiment	15	25	4	6,8	6	10	5	8,5	3	5,1	1	1,7
Built up prototype	3	5,1	3	5,1	5	8,5	4	6,8	3	5,1	1	1,7
Produce	1	1,7	4	6,8	2	3,4	4	6,8	2	3,4	1	1,7
Market launch	3	5,1	4	6,8	5	8,5	4	6,8	3	5,1	2	3,4
Analyse utilization	3	5,1	4	6,8	4	6,8	4	6,8	3	5,1	2	3,4
Analyse decommission	3	5,1	4	6,8	4	6,8	4	6,8	3	5,1	2	3,4

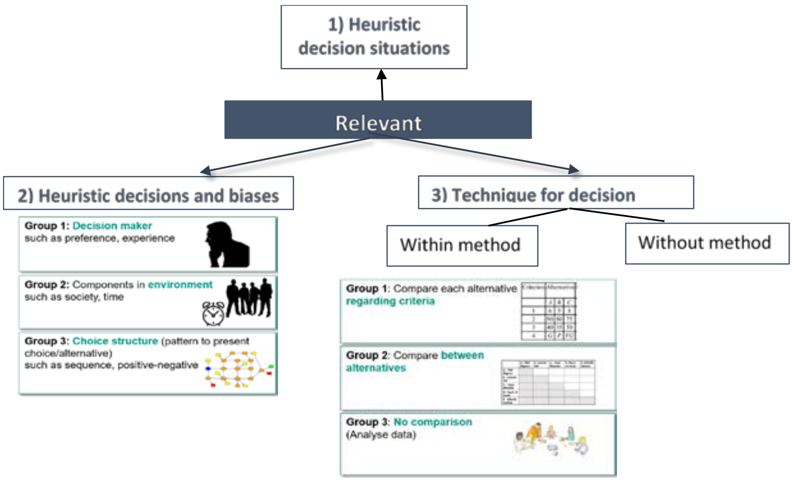


Figure 4.15: Overview of 3 components related to heuristic decisions and biases in product development

These three components, that are heuristic decision situations, heuristic decisions and biases, and technique for decision, are used to explained characters of heuristic decisions and biases in product development.

Types of decision such as systematic or heuristic should be specified in the first step of decision making. This step helps the researcher to focus only on the heuristic decisions instead of all decisions. This is the first component that should be identified at the beginning step.

Within that decision situation, a type of heuristic decisions and biases is the second component that should be identified and analysed using the resource of biases. Analysing heuristic decisions and biases from the resources can help the researcher to understand characters of heuristic decisions and biases that influence decision making in product development.

The technique that is used to make a decision is the third component in this investigation. As described in the previous part, heuristic decisions and biases can be appeared even using the design method or not. Therefore, this is one components that is used to describe heuristic decisions and biases in product development.

However, the connection between these 3 components is not investigated and explained in the previous studies. The researcher then analyse and propose 20 possibility situations and examples as shown in

Table 4.13 based on these 3 components. These situations are an assumption regarding information from the previous studies, literature review, examples from different research fields, and experience.

Table 4.13: Twenty possibility connections of 3 components and examples that can represent the appearance of heuristic decisions and biases in product development

	1) Heuristic decision situations			2) Heuristic decisions and biases		3) techniques to make a decision		
No	Activities of product development	Problem-solving activity	Decision situation	Cause	Decision bias	Technique	Method	Short explanation
1	Detect profiles	L	Select product profile	Group3: Choice structure	Decoy effect	No method	no method	2 alternatives have a similar idea but a different level of quality, 1 alternative is unique
2	Detect profiles	L	Select product profile	Group2: Environment	Representativeness	Group1: Compare each alternative regarding criteria	Persona	Information from Persona can lead decision makers to ignore other information and make a decision based only on information from Persona
3	Detect profiles	L	Select product idea	Group1: Decision makers	Status quo bias	Group2: Compare between alternatives	Pairwise comparison (Paarweiser Vergleich)	Decision makers make a current decision based on the previous selection (select/reject the same alternative)
4	Detect profiles	L	Select product profile	Group2: Environment	Anchoring or focalism	Group1: Compare each alternative regarding criteria	Influence matrix/ Consistent matrix	Decision makers define the current value (impact value) based on the initial number that defined in the previous evaluation when the content in the previous evaluation is nearly similar to the current evaluation

Selected to be investigated in experiments

No	1) Heuristic decision situations			2) Heuristic decisions and biases		3) techniques to make a decision		Short explanation
	Activities of product development	Problem-solving activity	Decision situation	Cause	Decision bias	Technique	Method	
5	Detect ideas	L	Select concept idea	Group1: Decision makers	Availability heuristic	No method	no method	Decision makers make a decision based on their own experience
6	Detect ideas	L	Select concept idea	Group2: Environment	Anchoring or focalism	Group1: Compare each alternative regarding criteria	decision matrix	Decision makers define the current value (impact value) based on the initial number that defined in the previous evaluation when the content in the previous evaluation is nearly similar to the current evaluation
7	Detect ideas	L	Select concept idea	Group1: Decision makers	Status quo bias	Group2: Compare between alternatives	Pairwise comparison	Decision makers make a current decision based on the previous selection (select/reject the same alternative)
8	Detect ideas	L	Select concept idea	Group1: Decision makers	IKEA effect	No method	no method	Decision makers select an alternative that they are created and developed
9	Detect ideas	L	Select concept idea	Group1: Decision makers	Sunk costs fallacy	No method	no method	Decision makers select an alternative that they take a lot of effort on it.
10	Model principle solution and embodiment	L	Select technical solution	Group3: Choice structure	Decoy effect	No method	no method	2 alternatives have a similar idea but a different level of

No	1) Heuristic decision situations			2) Heuristic decisions and biases		3) techniques to make a decision		Short explanation
	Activities of product development	Problem-solving activity	Decision situation	Cause	Decision bias	Technique	Method	
								quality, 1 alternative is unique
11	Model principle solution and embodiment	L	Select technical solution	Group1: Decision makers	IKEA effect	Group1: Compare each alternative regarding criteria	FMEA	Decision makers provide a high score to the alternative that they are developed
12	Model principle solution and embodiment	L	Select technical solution	Group1: Decision makers	Status quo bias	Group2: Compare between alternatives	Pairwise comparison	Decision makers make a current decision based on the previous selection (select/reject the same alternative)
13	Model principle solution and embodiment	L	Select technical solution	Group2: Environment	Anchoring or focalism	Group1: Compare each alternative regarding criteria	FMEA	Decision makers define the current value (impact value) based on the initial number that defined in the previous evaluation when the content in the previous evaluation is nearly similar to the current evaluation
14	Model principle solution and embodiment	L	Select technical solution	Group2: Environment	Bandwagon effect	Group2: Compare between alternatives	Take the best	Decision makers take the most favorite alternative based on group thinking or group opinion
15	Model principle solution and embodiment	A	Which information do we need for	Group1: Decision makers	Confirmation bias	No method	no method	Decision makers find and select the information that

No	1) Heuristic decision situations			2) Heuristic decisions and biases		3) techniques to make a decision		Short explanation
	Activities of product development	Problem-solving activity	Decision situation	Cause	Decision bias	Technique	Method	
			the specific function					supports their idea
16	Model principle solution and embodiment	A	Which information do we need for the specific function	Group3: Choice structure	Frequency illusion	No comparison	Brainstorming	Decision makers find and select the information that usually appears when searching for information even it is not important
17	Detect ideas	A	To identify criterion for gathering idea such as advantage for the future, a benefit for the provider	Group1: Decision makers	IKEA effect	No comparison	Brainstorming	Decision makers define and select criteria that support their ideas
18	Detect ideas	A	To identify criterion for gathering idea such as advantage for the future, a benefit for the provider	Group1: Decision makers	Focusing effect	No comparison	Brainstorming	Decision makers define and select criteria based only on one aspect such as only production time, company's policy, or innovation
19	Manage knowledge	E	Whether the information is important for collecting in the database	Group1: Decision makers	Availability heuristic	No comparison	Checkliste generieren (generate checklist)	Decision makers generate the checklist based on experience and their memories about available information

No	1) Heuristic decision situations			2) Heuristic decisions and biases		3) techniques to make a decision		Short explanation
	Activities of product development	Problem-solving activity	Decision situation	Cause	Decision bias	Technique	Method	
20	Manage knowledge	E	Whether the information is important for collecting in the database	Group1: Decision makers	Sunk costs fallacy	No method	no method	Decision makers try to collect all information to avoid losing any information that is found even the information does not necessary

At the beginning, heuristic decision situations based on iPeM model are selected. Most of them are in the engineering activity of product development and in the selection of solution (L) in problem solving activity. Decisions in these situations usually made by heuristic decisions because of insufficient information and time limitation. Within each situation, a specific type of heuristic decisions and biases based on the resource is analysed and presented. Components in each situations are used to define a type of heuristic decisions and biases that possibly appear in that situation. For example, anchoring bias usually appears when decision making is dealing with number and adjustment. This components also link to the technique to make decision in the third component. The assumptions are proposed based on the components of methods and characters of heuristic decisions and biases.

Regarding limitation of research time, only 4 possible situations and examples were selected to evaluate in experiments and investigate in details to understand the influence of heuristic decisions and biases in product development. Even though only 4 situations are selected to proof in the experiments, these 4 situations can represent all possibility of heuristic decisions and biases in product development based on different groups of heuristic decisions and biases, and techniques for decision making. Characters of 4 selected situations are described in the following:

- Situation 1 presents heuristic decisions and biases from choice structure when selecting solution without using the method

- Situation 2 presents heuristic decisions and biases from environment when selecting solution using a method by comparing each alternative regarding criteria.

- Situation 3 presents heuristic decisions and biases from decision makers when selecting solution using a method by comparing between alternatives.

- Situation 4 presents heuristic decisions and biases from choice structure when selecting solution using a method by comparing between alternatives.

4.6 Conclusion

Results from Chapter 4 propose ideas about influences of heuristic decisions and biases in product development based on literature review, observation, and investigation in the simulated environment (Live Labs) and the real environment (company). Information from different resources of literature provide a fundamental knowledge to be more understanding about heuristic decisions and biases in product development, which can be classified into 3 components. These three main components are heuristic decision situations in product development, heuristic decisions and biases, and techniques to make a decision. Information in each component is classifies and summarized in main topics. Heuristic decision situations are classified based on product activities and problem-solving activities in iPeM model. Heuristic decisions and biases are grouped into 3 groups based on a resources of biases, which are the decision maker, environment, and choice structure. Techniques to make a decision are illustrated into 2 groups that are with and without design methods. Within the design methods, each method can be classified in to 3 groups based on procedures to evaluate alternatives. These three groups are comparing each alternative regarding criteria, comparing between alternatives, and no comparison.

Connections between these 3 components were then proposed to show possible situations of heuristic decisions and biases in product development. Based on time limitation in the research, 4 possible situations are selected to proof concept ideas and be able to understand an appearance of heuristic decisions in product development. Design experiments for these 4 possible situations will be planned and performed in Section 5.

5 Evaluation of heuristic decisions and biases in product development

This chapter aims to proof four possible situations of heuristic decisions and biases in product development as described in the previous chapter. Each experiment is designed to simulate a decision situation in activities of product development under different environment and methods. Results from these experiments are then analysed to understand an influence of heuristic decisions and biases to the decision making. An overview of these experiments is explained in Table 5.1.

Table 5.1: An overview of 4 experiments to investigate 4 possibility situations of heuristic decisions and biases in product development.

No.	Experiment	Objective
1	Investigating an influence of decoy effect in a product profile selection activity	Investigate the influence of decoy effect by proposing 2 alternatives and 3 alternatives of product profile.
2	Investigating an influence of representativeness in a product profile selection activity	Investigate the influence of representativeness heuristic based on the description in the Persona method during selecting a product profile
3	Investigating an influence of status-quo bias in a product idea selection activity	Investigate the influence of status-quo bias by proposing a rejected alternative or selected alternative to the next comparison using the pairwise-comparison technique..
4	Investigating an influence of anchoring and adjustment in the scenario method when defining impact value in the influence matrix	Investigate the influence of anchoring and adjustment when evaluating impact values in each pair of impact factors to create an influence matrix in the scenario method.

5.1 Investigate the influence of decoy effect in a product profile selection activity

This experiment was designed based on the assumption that the decoy effect caused by a choice structure can influence the decision maker to be biased when selecting the solution without the supporting method in the product finding activity.

An idea to make this experiment comes from the studies from Ariely's (Ariely & Jones, 2008) study in the economic field. He made the experiment about a web appearance of a magazine at MIT's Sloan School of Management with 100 students in a control group and a study group. Two types of subscriptions that they could buy were shown to the control group. These two options were 1) an annual online version of a magazine for $59 and 2) a print and online version of the magazine for $125. Both conditions were a one-year subscription. The third option was added to the control group, which is a senseless version with a pure print version for $125. This option should not be bought since the price was similar but posed as a lower benefit than the print and online option. Figure 5.1 shows the experiment design and results of selection in the control group and in the study group.

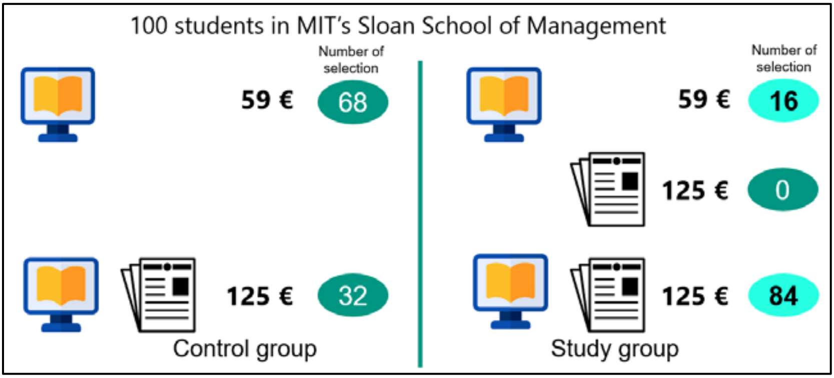


Figure 5.1: Experiment design to investigate decoy effect in an online magazine subscription from Ariely's study (Ariely & Jones, 2008)

In the study group that 3 options were presented, sixteen students selected the annual online version of a magazine for $59 in option 1. Eighty four students selected the combination option with the print and online version for $125. However, no student selected the third senseless option. On the other hand, sixty eight students in the control group that are presented with 2 options selected the annual online version for $59; and thirty two students selected the combination option. When analyzing the second and third option with the same price but different benefit, the decision maker focused on the second option that provided a better benefit than the other option.

The online subscription then becomes less interesting because of little information or no comparison, which finally makes the second option with the combination benefit for $125 to be the best or better option than others. Results from this study implied that people don't decide on the absolute, rather the relative merit of a solution and are biased by choices. The experiment from Ariely makes an inspiration to the researcher to apply a similar concept idea to the PGE-Product Generation Engineering field.

The experiment was then performed to proof an appearance of heuristic decisions and biases from choice structure when selecting solution without using the method, which was proposed in Situation 1 in Section 4. Participants in this experiment were assumed to be in an Innovation workshop (Inno5) that aims to develop a product regarding product development processes and activities. The participants started the experiment by watching the video that described steps of product development and creativity method to develop the next generation of apple peeler, which was the main task in this workshop. The reference product of the apple peeler was presented and explained. Normally, the new product is usually developed from the reference product by keeping the part that is valuable and adapting and improving some parts of performance and quality.

Examples of information in the video are shown in Figure 5.2.

Figure 5.2: Examples of information in the video describe the process and activity in product development such as analyzing the reference product, analyzing and creating a persona, and evaluating function values.

Then students in the control group and the study group were presented 2 and 3 idea options of the next generation of apple peeler. They had to analyze the components, decide on the direction of the new product, and select the voted best idea option.

Two options in the control group were an electrical driver option and a drip tray option. These two options are reasonable solutions with different idea directions. The added third option was a gasoline engine. This option was a similar idea like the electrical driver in the first option, (which focused on the driving system), but was senseless. Oil in a gasoline engine can contaminate an apple, which is unsafe and impractical. These three options were shown in Figure 5.3.

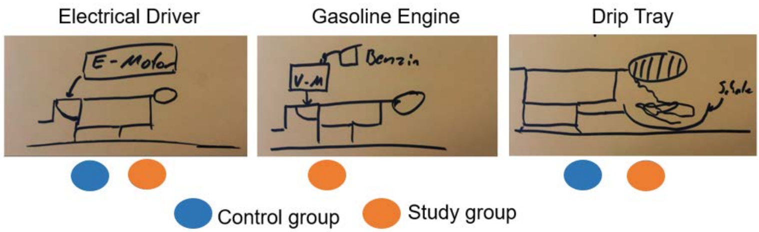


Figure 5.3: Three idea options for the next generation of apple peeler in the control group and the study group

This experiment was tested in 2 pre-studies before applying it to the main study as shown in Figure 5.4.

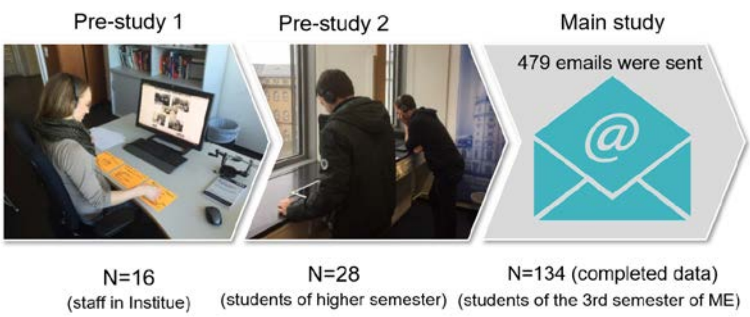


Figure 5.4: Processes of experiment

The first pre-study was tested with the institute's staff (n=16) at the IPEK; the second pre-study was tested with the students of a higher semester (>3rd semester) of mechanical engineering (n=28). Participants in both groups used an online survey to participate in this experiment. Results and feedbacks from the pre-study help us to improve the experiment to be more understandable for the participants.

In the main study, the participants were the students of the third semester of mechanical engineering (n=479). They were divided randomly in the study group and the control group and asked to participate in the experiment by email. Even though participants in the pre-study and main study are different. The expertise of participants did not influence in this experiment because all basic information was provided in the video and experiment. The survey was available for 2 days after emails were sent to prevent a discussion between the control group and the study group. Only 164 students responded to this survey; 134 results were complete after data cleansing with regard to incomplete data sets, incomplete viewing of the video (t<50 sec), and temporal outliners in the selection (t>200 sec). These 134 results came from 69 participants in the control group and 65 participants in the study group.

An average time that participants performed this experiment was 36 sec in both groups with a standard deviation of 16 sec. Therefore, there were no significant differences between both groups in decision-making time even when the third alternative was added in the study group. This implies that the third alternative did not affect decision-making time. Based on the idea selection behavior in the control group, 36% of participants selected the electrical driver option in the first option; and 64% of participants selected the drip tray option in the second option. The percentage of participants in the study group who selected the electrical driver, drip tray, and gasoline engine were 46%, 49%, and 5%, respectively. These results were shown in Figure 5.5.

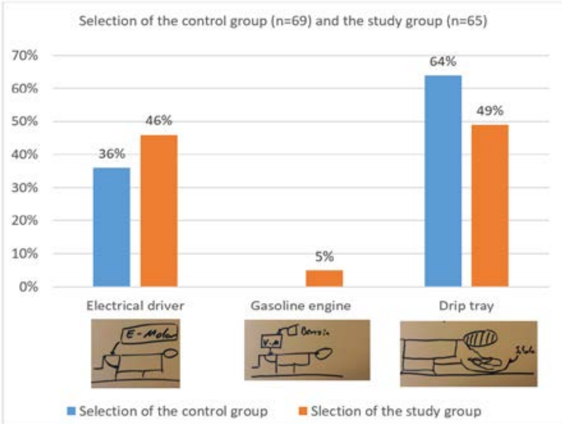


Figure 5.5: Results of idea selection for the next generation of apple peeler in the control group with 2 options and the study group with 3 options

From the result, the number of participants who chose the electrical driver was increasing from 36% in the control group to 46% in the study group. This increasing number suggests that the selection between the electrical driver and the drip tray in the study group are nearly the same with 46% and 49%. There were a few participants who selected the gasoline engine (5% of participants in the study group). The changing number of selections between the electrical driver and the dip tray in the control group and the study group showed that the senseless idea (gasoline engine) affected the decision makers to make decisions. The third option (gasoline engine) that has the same direction idea but worse in quality than the first option (electrical driver) can induce the decision makers to focus on the first alternative. Therefore, the number of selections in the study group who selected the first option was increasing.

When analysing results regarding duration time of decision making, an average of time consumption is 36 seconds. This duration was long enough to be intuitively answered. Moreover, no difference in the amount of time to make a decision in both groups showed that the types and number of alternatives did not affect the participants to make a decision.

In the statistical analysis, the significant difference between the result in the control group and the result in the study group is 0.109 or 89.01% difference between these groups. Even the significance between both groups is higher than the standard number in behavioral research (<0.05). This result indicates an appearance of the decoy effect in product profile selection activity in product development. The researcher can claim that the decoy alternative or gasoline engine alternative in this experiment is an unfavourable or senseless idea for the new product generation and can suggest a similar, better idea to be prioritized and selected more frequently. A few participants did take interest in the third option, (the gasoline engine) of this experiment as it could possibly be suitable for new product generation.

In conclusion, this experiment showed an example of heuristic decisions and biases caused by the choice structure when making a decision to detect potential product profile activity in product development without design methods to support decision making. Even a conclusion cannot be definitely made based on the result from this experiment about an influence of heuristic decisions and biases in product development, this result shows a hint of heuristic decisions and biases in a decision that should be aware of it when assessing the quality of solution alternatives and try to avoid a decision error.

5.2 Investigate an influence of representativeness in a product profile selection activity

This experiment (Bursac, N., Tanaiutchawoot, N., Rapp, S., Albers, A., Breitschuh, J., & Eckert, C., 2018) was designed to proof the second possible decision situation in Section 4. Within an assumption of this decision situation, the representativeness heuristic caused by an environment possibly influence the decision maker to be biased when selecting the solution based on the persona method in the product finding activity.

This experiment was designed by combining the study called “Tom W’s Specialty” in the economic field by Kahneman and the previous experiment in Section 5.1. In the “Tom W’s Specialty” study, the participants had to choose the field that Tom W graduates in. Without any description, they normally made a decision depending on the base rate and guessed that his graduation was in humanities and education rather than computer science or library science because students in the first group were higher than other groups. The participants changed their views however, once learning that his character was described as: having little affinity or sympathy for others, disliked interacting with others, and preferred neat and tidy systems and corny puns.

These personality traits were not appropriate for a field in humanities and education but was more suitable for computer and library science. His character seemed to fit the small groups more than the large group, called an anti-base-rate character.

In product development, decisions usually rely on available information, which may be also anti-base-rate. Two studies in this experiment illustrate this behavior in activities of product development field. Different personas were used in these 2 studies to evaluate the influence of representativeness in the product profile selection for the new product generation.

In the first study, the participants were students who were in the product development lecture that is organized by our institute annual. They watched the video that aimed to let the participant understand the reference product of apple peeler, processes and design activity in product development. Most contents in this video were similar to the contents in the previous experiment. Only a description of Hans Hitech in Figure 5.6 was added.

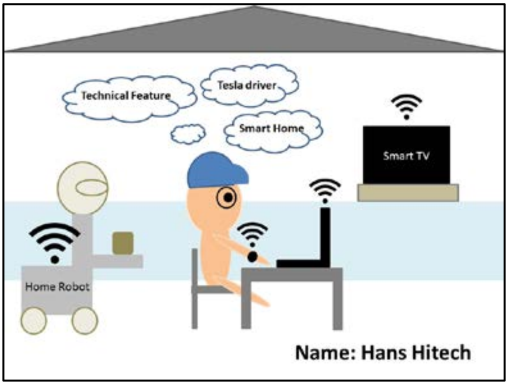


Figure 5.6: One of five personas that implemented in the video (Bursac, N., Rapp, S., Albers, A., Breitschuh, J., & Tanaiutchawoot, N., 2017)

In the video, Hans Hitech was described as one of five personas who is fascinated by technology and automation. He is a Tesla driver. He is working hard and likes to develop new things. He likes to eat and work at the same time. Many people call him "a gadget person". After watching the video, all participants had to select the most preference option that was suitable for the new product generation of apple peeler. These 2 options are the electrical driver and the drip tray. Based on the similar options between the control group in the first experiment and participants in this experiment, the results of idea selection in the control group in the first experiment were compared to the result from this group who got an extra description of Hans Hitech. Even though five personas were claimed in the video, only Hans Hitech was described and presented to participants. Other personas did not present to participants. Components of experiment in the control group and the study group are shown in Figure 5.7.

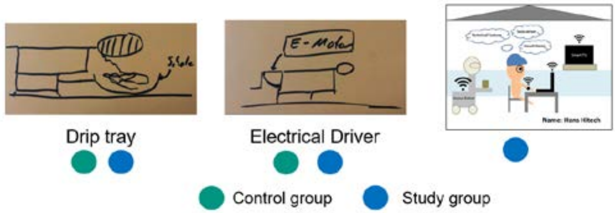


Figure 5.7: Components in the first study of this experiment between the control group and the study group

Participants in this experiment used the ARS nova tool (*ARSnova – Audience Response System für innovative Lehre;* Quibeldey-Cirkel et al., 2013) to select the favorite idea by scanning the QR code and answering it individually. Only 70 participants could completely answer questions in time. Results from both groups are shown in Figure 5.8.

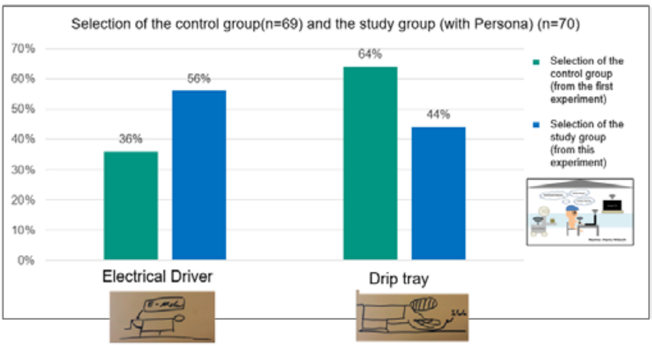


Figure 5.8: Results of idea selection for the next generation of apple peeler in the control group without the description of persona and the study group with the description of the persona

The result from Figure 5.8 shows 56% of participants in the study group selected the electrical driver option, which is increasing from 36% of participants in the control group who selected the same option. This result implies that a description of Hans Hitech that supports the electrical driver option can influence decision making to concentrate on the electrical driver option rather than the drip tray option. The significant difference in selection behavior between 2 groups based on statistical analysis is 0.006873, which is lower than 0.05. That means the decision making between the two groups is different. In other words, the description of persona (Hans Hitech) affects the participant to make a decision by selecting the option that is supported by the description and ignoring other information such as base-rate or possibility. Moreover, participants focus only description from Hans Hitech without questioning about the description of other personas.

The second study was then done in the same group of participants in study 1 who were in the product development lecture to confirm the result in the first study. The experiment in this study aims to confirm the influence of persona to the decision making in the product profile selection by providing different description of personas to different groups with the same alternatives of product profile as shown in Figure 5.9.

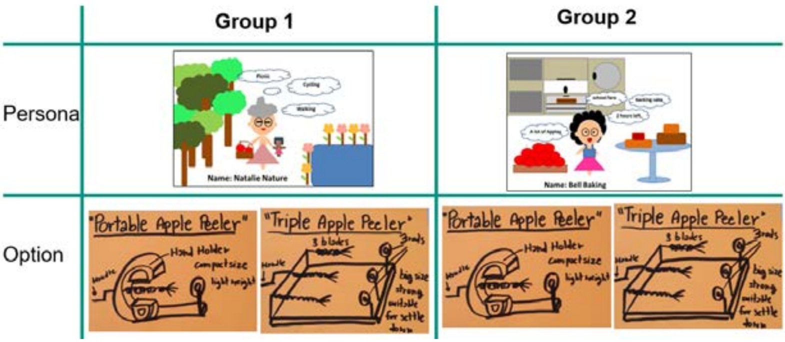


Figure 5.9: Two new options for the new product generation of apple peeler and two personas in an experiment in study 2

Participants in this study were separated into two groups by the position of their seats that were on the right side or on the left side regarding the middle of the lecture room. Two new options for the next product generation of apple peeler that were a portable apple peeler option and the triple apple peeler were presented. However, different personas were described in both groups as showing in Figure 5.9. Natalie

Nature was described in the first group; Bell Baking was described in the second group. Natalie Nature was described as the woman who lives in the countryside with her child. They enjoy a picnic in the woods. Her child likes apples but dislikes like apple peel, so Natalie always has to peel them. This persona was created to support the portable apple peeler option. Bell Baking, on the other way around, likes baking and will bake something every time when the school has a fair. This time she has to bake several apple pies for children, teachers, and parents. Regarding this description, the description of Bell Baking seems to be fit with the triple apple peeler option. That means the participants in both groups got different information or representativeness.

Because of the limited time of the experiment (around 1 minute), only 45 answers from the first group and 39 answers from the second group were completed. The result of the second study in this experiment is shown in Figure 5.10.

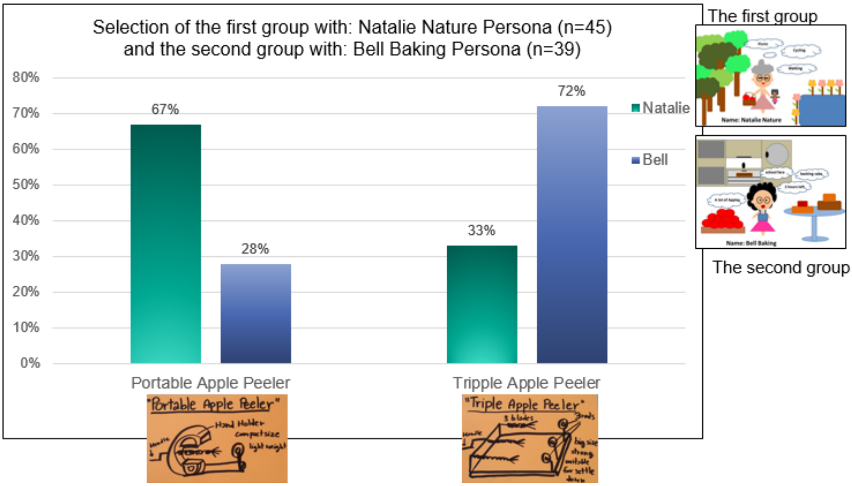


Figure 5.10: Results of idea selection for the next generation of apple peeler in the first group with the Natalie Nature persona and the second group with the Bell Baking persona

The result in the first group who got the description of Natalie Nature shows that 67% of participants selected the portable apple peeler option for the next product generation of apple peeler. Only 33% selected the triple apple peeler. On the other hand, 28% of participants in the second group who got the description of Bell Baking selected the portable apple peeler option for the next product generation of apple peeler. 72% of participants in this group selected the triple apple peeler option that is suitable for Bell Baking; the description of persona in this group. A result from statically analysis showed a significant number with 0.000151. That means results from both groups have significantly difference. Therefore, the description of persona affects the decision making when selecting the product profile for the next product generation. The result in the second study is also similar to the result in the first study.

The result from both experiments shows the influence of presented information, which lead the decision makers to focus only on that information and ignore other possibility and information. For example, an apple peeler is normally used in a bakery store that requires a fast process with a bunch of peeled apples. A description of Natalie Nature is an example from a small group of the customer but not the main group of customers. Selecting an idea regarding the description from Natalie Nature, therefore, is an anti-base rate. The first study showed the influence of the persona's description from Hans Hitech. Without the description of Persona, the participants were interested in the drip tray option. After implementing the description of Hans Hitech, most decision makers selected the electrical driver option. This result supports an assumption that presented the specific information can affect the decision makers to be biased. Examples from these studies; therefore, explain the appearance of heuristic decisions and biases from the environment to the decision making during selecting an idea of product profile for the next product generation with the persona method. Results from this experiment are a clue to show an appearance of heuristic decisions and biases in the situation as assumed in the second possible situation in Section 4. The decision makers should be aware of this influence when analyzing information to select the solution.

5.3 Investigate the influence of status-quo bias in a product idea selection activity

This experiment was designed based on an assumption from the possible situation 3 in Section 4. In this situation, the status-quo bias caused by a decision maker is claimed to influence the decision maker to be biased when selecting the solution using a pairwise-comparison method in the idea selection activity.

Pairwise-comparison method is one of the well-known methods to prioritize alternatives and select the final solution by comparing alternatives in pairs until all alternatives are pairs. The alternative that has the highest score or selected the most will be the best alternative. This method requires an intuitive decision to evaluate alternatives, which sometimes inconsistency in decision making. Different techniques and procedures to rank alternatives can lead to different solutions (Dym, Wood & Scott, 2002). Position and time to present alternatives can influence the decision behavior. The alternative that is on the left position seems to be selected more often than the alternative that is in the right position. At the same time, if one alternative is presented longer than the other alternative, that alternative has more chance to be selected than the other one. Moreover, if the result from the previous selection is longer than the current selection, the decision maker will try to repeat the current selection (Krajbich, Armel & Rangel, 2010; Wimmer & Shohamy, 2012). This behavior is similar to the description of status-quo bias. The decision maker who has a status-quo bias will try to keep selecting his/her decision regarding the current state. Selecting something new is perceived as a loss.

Based on this information and the assumption of the possible decision situation 3 in Chapter 4, this experiment is designed that aims to present heuristic decisions and biases during comparing alternatives regarding different techniques to present alternatives in pairs. In general, alternatives are presented in pairs based on 2 methods: the sequential method, and the random method as shown in Figure 5.11.

Alternatives

A B C D

	Pairwise comparison method			
Sequence	Sequencial method		Random method	
	1st alternative (Pivot)	**2nd alternative (Comparator)**	**1st alternative**	**2nd alternative**
1st	A	D	A	B
2nd	A	D	C	D
3rd	A	C	D	A
4th	B	D	B	C
5th	B	C	D	B
6th	C	B	A	C

Figure 5.11: General methods to compare alternatives in pairs

Based on the sequential method, alternatives are compared by fixing one alternative that is called a pivot alternative. Then the other alternative called comparator is changed until all comparators are compared. After that, the new pivot is selected and compared to all comparators. Another method is the random method. A pivot and a comparator are selected randomly until all alternatives are compared.

In this experiment, the researcher modified the sequential method to present alternatives in each pair. However, techniques to select the pivot and the comparator are different. Two techniques of selecting the pivot in each pair as shown in Figure 5.12 come from the character of status-quo bias.

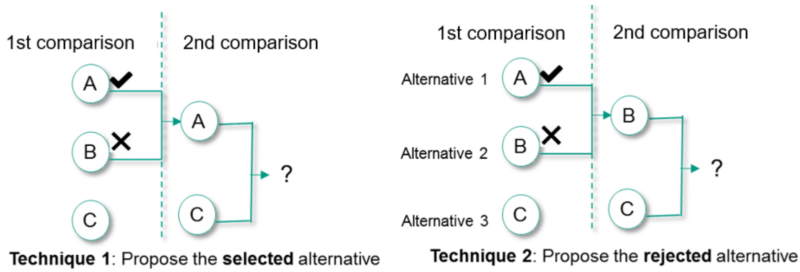


Figure 5.12: Two techniques (present selected alternative, rejected alternative) to present alternatives in each pair

For the first technique, the alternative that was selected in the previous comparison will be the pivot in the current comparison. For the second technique, the alternative that was rejected in the previous comparison will be the pivot in the current comparison. These 2 techniques are developed based on the assumption that a current selection behavior can be influenced by the previous selection behavior. If the third alternative is compared with the alternative that was selected in the previous comparison (with technique 1), a chance that the third alternative is selected is low. On the other hand, if the third alternative is compared with the alternative that was rejected in the previous comparison (with technique 2), a chance that the third alternative is selected is high. This experiment was done with 60 master' students in mechanical engineering at KIT via email. The task was to select the most favorite concept idea for the first generation of beer transportation robot. This robot has to be able to carry 6 bottles of beer from one cafe in the university to a small garden near one building, which is around 240 meters from the starting point to the ending point. The maximum delivery time is 10 min; the robot should possibly be sold for

€3000-€5000. Participants got this information from a video that explains all requirements, robot specifications, and 3 reference products of mobile robots. These 3 reference products have different technical solutions for a driving system but are also available for different applications. After the participants got all knowledge that was required to select the product idea for the first generation of beer transportation robot, 3 ideas in Figure 5.13 were presented in different sequences using the pairwise-comparison method based on the group that the participants belong to.

Figure 5.13: Three ideas of the first generation of beer transportation robot

Sixty-one students as mentioned above were separated into 2 groups. Participants in group 1 were 31 participants who compared alternatives using the first technique or Technique 1 in Figure 5.12. The other 30 participants were in group 2 and compared alternatives using the second technique or Technique 2 in Figure 5.12. Nevertheless, the first pair of comparison in both groups started to the comparison between the Track-wheel robot and the 3-wheel robot. All possibility comparisons of each pair based on the selection behavior in group 1 and group 2 were shown in Table 5.2and Table 5.3, respectively. For an example from case 1 in Table 5.2, when the participant selects a track-wheel robot in the first sequence of comparison, the same alternative or the track-wheel robot will be presented with the third alternative or a 4-wheels robot in the second sequence of comparison. It does not matter that which alternative is selected in this round, the 3-wheels robot and the 4-wheels robot will be presented in the third sequence of comparison.

Table 5.2: All possibility comparison of each pair based on the selection behavior in group 1 with the selected alternative technique

	Possibility of selection							
1st step	Track-wheel robot				3-wheels robot			
2nd step	Track-wheel robot		4-wheels robot		3-wheels robot		4-wheels robot	
3rd step	3-wheels robot	4-wheels robot	3-wheels robot	4-wheels robot	Track-wheel robot	4-wheels robot	Track-wheel robot	4-wheels robot
Possibility No.	1	2	3	4	5	6	7	8

Table 5.3: All possibility comparison of each pair based on the selection behavior in group 2 with the rejected alternative technique

	Possibility of selection							
1st step	Track-wheel robot				3-wheels robot			
2nd step	3-wheels robot		4-wheels robot		Track-wheel robot		4-wheels robot	
3rd step	Track-wheel robot	4-wheels robot	Track-wheel robot	4-wheels robot	3-wheels robot	4-wheels robot	3-wheels robot	4-wheels robot
Possibility No.	1	2	3	4	5	6	7	8

After sending the survey via email, there were 22 respondents from group 1 and 25 respondents from group 2, which will be used to analyze the results. The result of this experiment was analyzed into 3 steps.

- In the first step, only results of selection in the second sequence of comparison from both groups were analyzed to show the decision behavior when the third alternative was presented with the alternative that was selected (group 1) or rejected (group 2) in the previous comparison. Details of this investigation are explained in Section 5.3.1.

- In the second step, the results of selection in the third sequence of comparison from both groups were analyzed separately. The investigation was performed based on the concept idea that people try to keep their behaviour to be stable. The alternative that was recently selected is more attractive than the alternative that was formerly selected. Results from this step present the decision behavior when both rejected alternatives (group 1) and both selected alternatives (group 2) were compared, which are presented in Section 5.3.2.

- In the last step, the results of absolute selection from 3 times of comparison were investigated in Section 5.3.3 to compare the final results between group 1 and group 2 that had different techniques to compare alternatives. The investigation in this step is aimed to illustrate an influence of techniques to present alternatives to the final result after finishing a comparison.

5.3.1 Investigate the decision behavior in the 2nd sequence of comparison between group 1 and group 2

This investigation focused on the 2nd sequence of comparison, which compared the third alternative to the alternative that was selected in the previous comparison (using proposing selected alternative technique), and the alternative that was rejected in the previous comparison (using proposing rejected alternative technique). The investigation was done based on the assumption that the new alternative when comparing with unfavourite alternative (rejected alternative) has a higher chance to be selected than the new alternative when comparing with the favourite alternative. Table 5.4 shows the results from 4 possibility cases in each group.

Table 5.4: Results of product profile selection in the first and second sequences of comparison in group 1 (proposing selected alternative) and group 2 (proposing rejected alternative)

	Possibility of selection							
Sequence	**Group 1: proposing selected alternative**				**Group 2: proposing rejected alternative**			
	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
1st	Track-wheel robot	3-wheels robot	Track-wheel robot	3-wheels robot	Track-wheel robot	3-wheels robot	Track-wheel robot	3-wheels robot
2nd	Track-wheel robot	3-wheels robot	4-wheels robot	4-wheels robot	3-wheels robot	Track-wheel robot	4-wheels robot	4-wheels robot
% of selection	50%	23%	13.5%	13.5%	28%	4%	40%	28%

Results from 4 cases in each group were then grouped into 2 types relying on the selection behaviour; but types of alternative are ignored. The decision maker in the first type selected the third alternative (4-wheels robot) in the second sequence of comparison, which included Case 3 and Case 4 in both cases. The decision maker in the second type made the same decision by selecting the same alternative in group 1 or rejecting the same alternative in group 2 as showing in Case 1 and Case 2. Results based on this consideration were then summarized and shown in Figure 5.14.

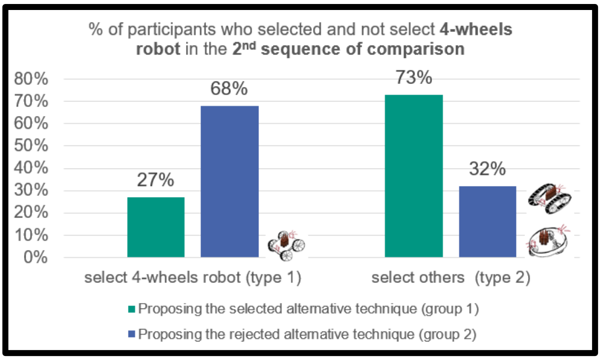


Figure 5.14: Selection behavior in the second sequence of comparison in group 1 (proposing the selected alternative technique) and group 2 (proposing the rejected alternative technique)

From the result, 73% of participants in group 1 selected the same alternatives in the second sequence of comparison as the alternative in the first sequence of comparison. Only 27% of participants changed their decisions to select the third alternative (4-wheels robot). Participants in group 2, on the other hand, selected the third alternative (4-wheels robot) with 68%. 32% of them selected the alternative that was rejected in the previous comparison. The results from both groups show a significant difference ($p<0.05$) based on the Fisher exact test. Results from this step imply that the previous selection behavior can influence the current decision behavior by keeping the constant stage of selection status. The alternative that was selected at the beginning of has a higher chance to be continuously selected in the next comparison than the new alternative. On the other hand, the alternative that was rejected at the beginning of comparison has more chances to be continuously rejected in the next comparison than the new alternative.

5.3.2 Investigate the decision behavior in the 3rd sequence of comparison when 2 selected or rejected alternative are compared

The second step was done to understand the decision behavior when the alternatives that have a similar status of selection (selected in group 1 and rejected in group 2) were compared as shown in Figure 5.15.

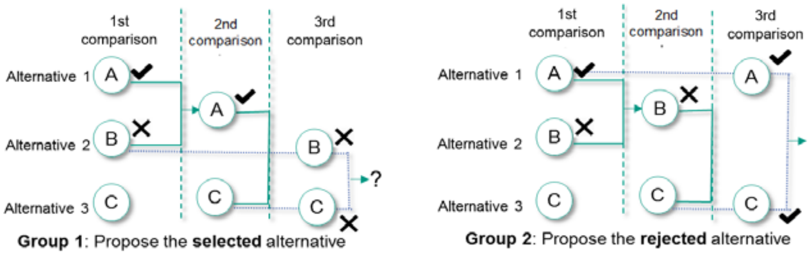
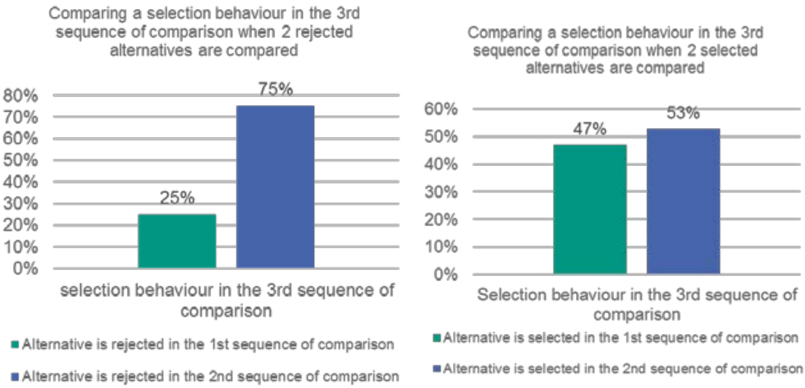


Figure 5.15: Patterns of comparison in each sequence of comparison in Group 1 and Group 2

This investigation was in the third sequence of comparison. The third sequence of comparison in group 1 compares 2 alternatives that have been rejected in the first or the second sequence of comparison. On the other hand, the third sequence of comparison in group 2 compares 2 alternatives that have been selected in the first or the second sequence of comparison. Results from four possible cases in each group are presented in Table 5.5. Other possibilities of selection are ignored because the selection in the first and in the second round were not the same. After that, these 4 cases were grouped into 2 types. The first type showed a similar selection behavior (selected-rejected) between the first and the third sequences of comparison. The second type showed a similar selection behavior (selected-rejected) between the second and the third sequences of comparison. Results based on these 2 types in group 1 and group 2 were presented in Figure 5.16 (1) and Figure 5.16 (2), respectively.

Table 5.5: Four Results of product profile selection from 4 cases in all three sequences of comparison in group 1 (proposing selected alternative) and group 2 (proposing rejected alternative)

	Possibility of selection							
Sequence	**Group 1: proposing selected alternative**				**Group 2: proposing rejected alternative**			
	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
1st	Track-wheel robot	3-wheels robot	Track-wheel robot	3-wheels robot	Track-wheel robot	3-wheels robot	Track-wheel robot	3-wheels robot
2nd	Track-wheel robot	3-wheels robot	Track-wheel robot	3-wheels robot	4-wheels robot	4-wheels robot	4-wheels robot	4-wheels robot
3rd	3-wheels robot	Track-wheel robot	4-wheels robot	4-wheels robot	Track-wheel robot	3-wheels robot	4-wheels robot	4-wheels robot
% of selection	14%	5%	36%	18%	20%	12%	20%	16%



1 2

Figure 5.16: Selection behavior in the 3rd sequence of comparison in group 1: proposing selected alternative technique (1) and group 2: proposing rejected alternative technique (2)

75% of participants in group 1 selected the alternative that was rejected in the second sequence of comparison. Only 25% of participants in group 1 selected the alternative that was rejected in the first sequence of comparison. On the other hand, the sequence of rejected alternatives did not influence decision behavior in the third round of comparison. The percentage of participants who selected the alternative that was selected in the first sequence of comparison were nearly similar to the percent of participants who selected the alternative that was selected in the second sequence of comparison with 47% and 53%, respectively. These results imply that the sequence of alternatives that were rejected affect to a selection behavior in the current comparison. The alternative that was rejected in the early comparison has a high chance to be rejected regarding the alternative that was rejected in the late comparison. One possible reason can be related to the memory of the decision maker. The alternative that was rejected in the early comparison is not in the decision maker's memory. The alternative that was rejected in the late comparison; therefore, has more chances to be selected because the decision maker can still remember this alternative. This behavior is also similar in group 2 that compared 2 selected alternatives. Even the selection behavior in 2 types are nearly similar, the alternative that was selected in the second round has more chance to be selected in the third round. However, more data is required to make a final conclusion.

5.3.3 Investigate the absolute selection based on different techniques to propose alternatives in a pairwise-comparison method between group 1 and group 2

Results from the first and the second step aim to analyze the decision behavior in each sequence of comparisons based on different techniques to present alternatives (proposing the selected alternative technique, proposing the rejected alternative technique). This step aims to find an absolute result based on different techniques to propose an alternative in a pairwise-comparison method. The absolute result comes from counting the number of times that each alternative was selected from 3 sequences of comparisons. If the alternative was selected 2 times, that alternative was the absolute selection. For example, if the track-wheel robot was selected in the first and the second sequences of comparison; the track-wheel robot would be the absolute selection no matter the selection in the third sequence of comparison was the track-wheel robot or others. Figure 5.17 shows a conclusion of absolute selection in both groups.

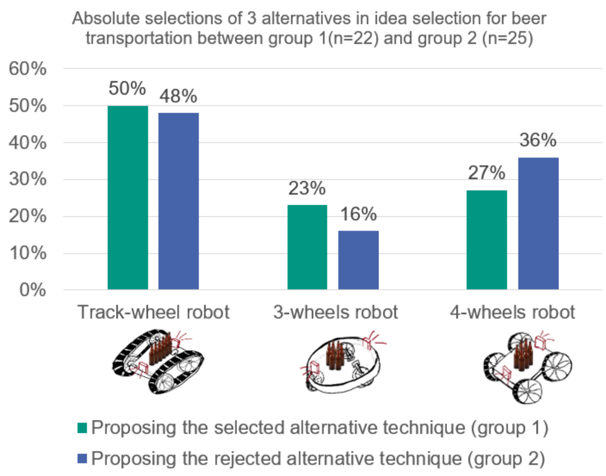


Figure 5.17: Absolute selection behavior regarding all sequences of comparison in group 1 (proposing the selected alternative technique) and group 2 (proposing the rejected alternative technique)

Results in Figure 5.17 show a similar trend of idea selection in both groups. The track-wheel robot was the most favorite idea in both groups with 50% and 48% of selection in group 1 and group 2, respectively. The second and third rank of selection were also similar. 27% of participants in group 1 and 36% of participants in group 2 selected the 4-wheels robot. Only 23% of participants in group 1 and 16% of participants in group 2 selected the 3-wheels robot. Even the ranking of selection in both groups is similar, but the percentage of participants who selected the 3-wheels robot in group 1 was higher than group 2. On the other hand, the percentage of participants who selected the 4-wheels robot in group 1 was lower than group 2. These results showed that the technique to compare the third alternative with the rejected alternative can increase the chance of selecting the third alternative. However, results from this step cannot be summarized as an influence of technique to present alternatives in the pairwise-comparison method. There were only 3 alternatives and 3 comparisons, which were too short to indicate an influence of proposing alternative techniques in the final ranking result. Therefore, increasing the number of alternatives in the pairwise-comparison method should be done in a further step.

In conclusion, 3 steps in this experiment presented examples of status-quo bias in the idea selection when using different techniques to propose alternatives in a pairwise-comparison method. People try to keep the current selection behavior as a baseline or a reference point and try to avoid changing the selection behavior. Examples in this experiment can then illustrate an appearance of heuristic decisions and biases caused by the decision maker when selecting the solution using the pairwise-comparison method in the idea selection activity, which was proposed in the possible situation 3 in Section 4. However, we need an approach to support decision making to avoid the decisions biases caused by heuristic decisions when analysing alternatives.

5.4 Investigate the influence of anchoring and adjustment in the scenario method when defining impact values in the influence matrix

This experiment was designed based on an assumption that the anchoring and adjustment caused by an environment usually occur when making a decision with a number or a value (Kahneman & Tversky, 2013). Based on this idea, this heuristic decision, therefore, can influence the decision maker to be biased when selecting the impact value to create an influence matrix in scenario activity (Erdmann et al., 2015), which is in the selection of product profile activity. The scenario is usually used to thinking about the possible future situation by collecting and analyzing the present information. Determining influence factors and analyzing the relationships between the factors are a part of processes to develop a scenario. All factors are listed in the column as the factors that give influences and in the row as the factors that get influences. Decision makers then define the influence value regarding the relationship of each pair. Figure 5.18shows an example of an influence matrix.

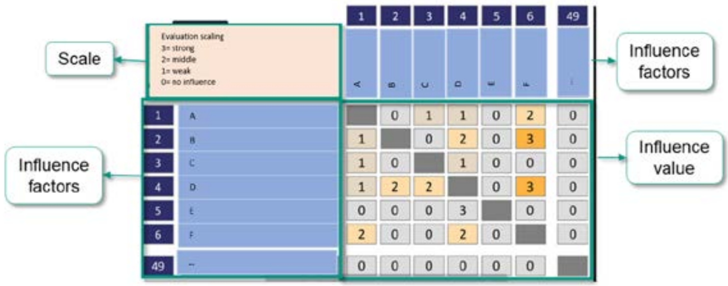


Figure 5.18: An example of an influence matrix

The decision makers normally compare the influence factors by fixing an influence factor in the column and change other influence factors in the row until all influence factors in the row are compared. Then the next influence factor in the column is compared to all influence factors in the row. This process is repeated until all influence factors in the row and column are compared. This method to present factors in each pair is the sequence algorithm.

In the experiment, the researcher investigates the impact of anchoring and adjustment heuristic when defining the influence value using the sequence and random algorithms to present each pair of influence factors. The sequence algorithm is a fundamental algorithm as previously explained. The random algorithm is an algorithm where no factor is fixed. Both factors are randomly changed until all pairs are evaluated. These 2 algorithms are compared based on an assumption that evaluating the influence value with the sequence algorithm will increase the appearance of anchoring and adjustment heuristic referring to the random algorithm. The digital tool as shown in Figure 5.19 was then developed to present influence factors with 2 algorithms and record the decision making during evaluating the influence value for each pair of influence factors to create an influence matrix.

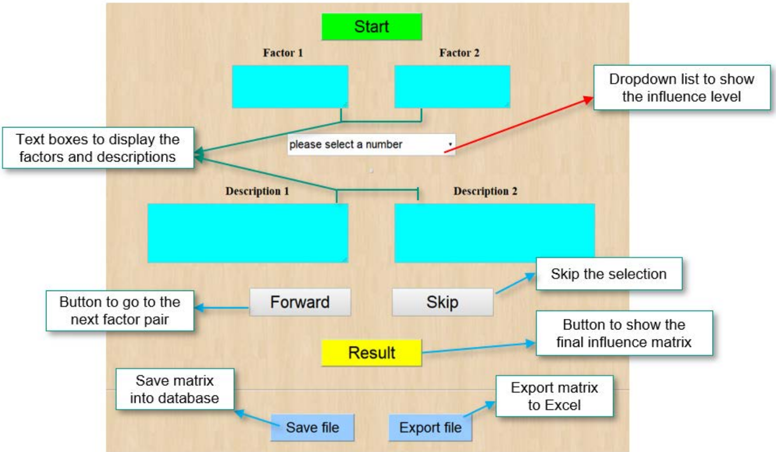


Figure 5.19: The digital tool to evaluate the influence value for each pair of influence factors (Zhongging, 2019)[1]

Twelve master students in the department of mechanical engineering participated in this experiment. The participants were separated into 2 groups. Six participants in group 1 started an evaluation with the sequential algorithm to present influence factors. After half of the comparison, the influence factors were presented using the random algorithm. On the other hand, 6 participants in group 2 started the evaluation with the random algorithm for half of the comparison. The other half of the comparison was done with the sequential algorithm. The algorithms to present the influence factors in each group were shown in Figure 5.20.

[1] Co-suprervisor of Master thesis

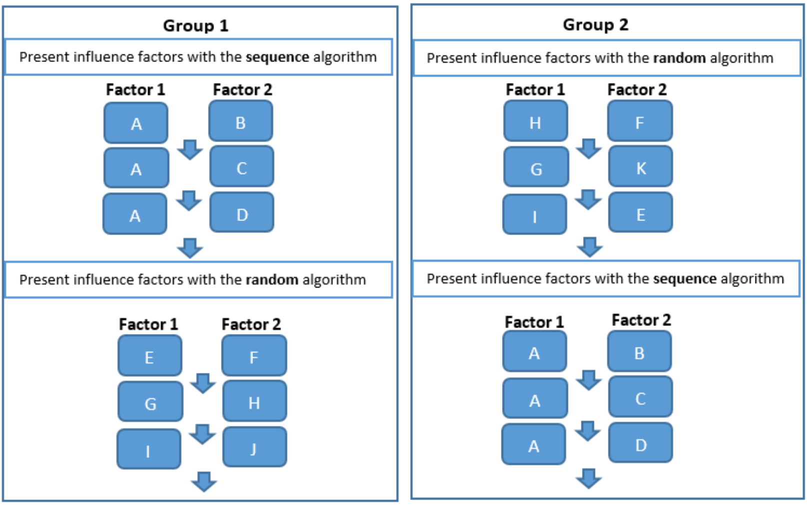


Figure 5.20: The algorithms to present the influence factors in Group 1 and Group 2

Participants in both groups were able to have an experience with these 2 algorithms. Moreover, the impacts of anchoring and adjustment in decision making regarding the sequence algorithm and random algorithm to present influence factors were compared in the individual and in a group.

All participants were assigned to evaluate the influence value by comparing 10 influence factors related to medical innovation. These 10 factors are the basic factors that are understandable from individual basic knowledge from the participants. After evaluating each influence factor, results were transformed into the decision matrix and calculated the gap in absolute value. The gap from the same row was plotted in one graph to show a trend of gap when fixing one influence factor and changing the other and when changing all influence factors in each pair. In the end, the gap values in each row were average to find an average value for each row. Figure 5.21 explains the processes to analyze the data.

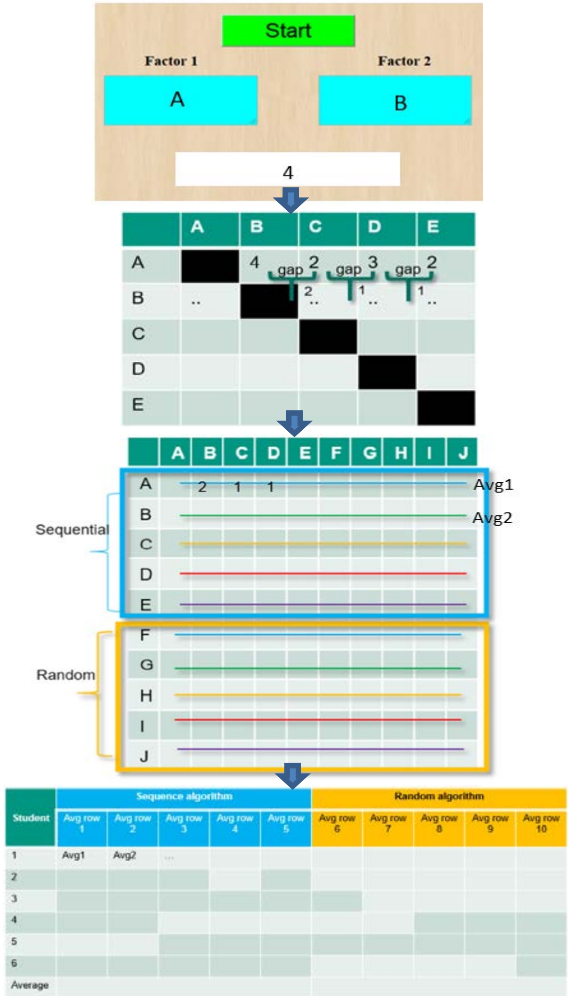


Figure 5.21: Processes to collect and analyze the results

Results from this experiment were analyzed in 2 steps:

1) Investigate the results from the same decision maker using different algorithms to present the influence factors. The concept idea in this investigation is to proof that

techniques to present information can make a decision in different way even the decision is made from the same decision maker. This behaviour happens because of the anchoring heuristic and adjustment.

2) Investigate the results from the same pairs of influence factors with different algorithms to present influence factors. This investigation is aimed to show that the results of evaluation from the same information can be different when different techniques are used to present information.

5.4.1 Results from the same decision maker using different algorithms to present factors

Figure 5.22 shows an example of a graph to present the gaps in each row when using the sequential algorithm and random algorithm to present the influence factors.

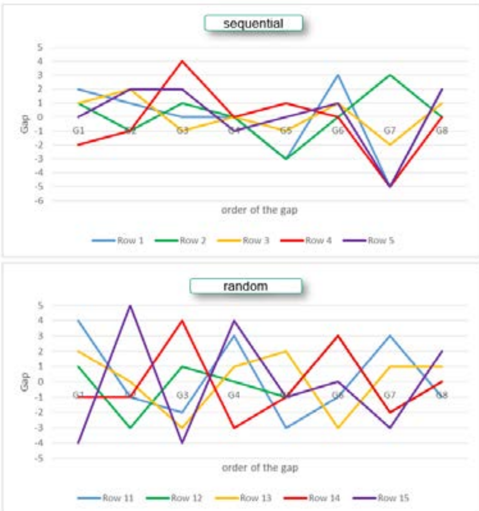


Figure 5.22: An example of a graph to represent the gaps in each row when using different algorithms to present influence factors

The graph in Figure 5.22 represents the result from 1 participant, which shows the changing of gap value. In the sequential algorithm, gap values from an individual row were nearly close and not rapidly changed as being seen in the amplitude of the graph. On the other hand, gap values in the random algorithm from the individual row were changed rapidly with a big number. This result implies that the decision maker tried to change an influence value with a constant value regarding the reference point or baseline when using the sequence algorithm to present influence factors. When using the random algorithm, the decision maker was not aware of the gap value between the previous and current evaluation. Therefore, the gap values were changed randomly with different amounts of changing value. Then results from each participant in group 1 and group 2 were summarized and averaged in Table 5.6 and Table 5.7 based on the techniques to present the influence factors, respectively.

Table 5.6: Results of average gaps in each row from 6 students in group 1

Student No.	**The average gap with a sequence algorithm**					**The average gap with a random algorithm**				
	Row 1	Row 2	Row 3	Row 4	Row 5	Row 6	Row 7	Row 8	Row 9	Row 10
1	1	1	1	1	1.4	1.08	1.1	1.12	1.14	1.17
2	1.37	1.37	1.5	0.75	1.37	2.12	0.75	1.87	0.87	0.75
3	2	1.12	1.12	1.62	1.62	2.25	1.37	1.62	1.87	2.87
4	1.37	0.37	0.75	0.75	0.87	0.5	0.5	0.75	0.62	1.25
5	1.62	0.62	0.75	1.25	1.37	1.25	1.12	1	0.87	0.75
6	1.87	1.25	1.75	1.75	1.5	0.87	2	1.5	2.5	1
Average	Sequence=1.238					Random=1.282				

Table 5.7: Results of average gaps in each row from 6 students in group 2

Student No.	**The average gap with a random algorithm**					**The average gap with a sequence algorithm**				
	Row 1	Row 2	Row 3	Row 4	Row 5	Row 6	Row 7	Row 8	Row 9	Row 10
1	1	1.5	1	1.25	0.75	1	0.87	0.87	0.5	1.25
2	2.37	1.37	1.87	2.12	1.25	2.12	1.12	1.5	0.62	2.25
3	2.5	2	2.25	1.25	1.62	1.25	1.5	1.25	1	0.75
4	2.25	1.12	1.75	1.12	1.62	1.12	0.75	1	0.75	0.62
5	0.87	1	1.12	0.62	0.87	0.25	0.62	0.75	0.75	1
6	1.12	1	1	1.5	1	1.25	1	1.5	0.87	0.87
Average	Random=1.4					Sequence=1.03				

Results from both tables show that an average gap of influence value when using the sequence algorithm (1.238 in group 1 and 1.03 in group 2) to present influence factors is lower than using the random algorithm (1.282 in group 1 and 1.4 in group 2). However, this difference in average value is not high in the first group. This can also be seen as no difference between both techniques in group 1 when comparing an average value. When analyzing in detail in each decision maker, an average gap over “2” in the random algorithm appears more often than the sequence algorithm. This is another clue that can be seen in the results from participants in group 2 and confirms that different algorithms to present influence factors can lead an appearance of anchoring and adjustment heuristic at different levels and affect the decision making in different ways.

5.4.2 Results from the same pairs of influence factors with different algorithms to present influence factors (different decision makers)

Results in this step were analyzed by comparing the results from different groups who used the different algorithms to present influence factors with the same pair of influence factors. An average gap in each row from 6 participants in each group was averaged and showed in Table 5.8 and

Table 5.9.

Table 5.8: Results of average gaps in row 1 to row 5 from 6 participants in group 1 and group 2

Row	Gap value with the sequence algorithm (group 1)		Gap value with the random algorithm (group 2)	
	Average gap value	Average standard deviation	Average gap value	Average standard deviation
1	1.67	2.17	1.69	2.03
2	1.02	1.35	1.29	1.66
3	1.42	4.73	1.44	1.81
4	1.06	1.37	1.27	1.74
5	1.35	0.99	1.46	1.21

Aver-age	1.3	2.12	1.43	1.69

Table 5.9: Results of average gaps in row 6 to row 10 from 6 participants in group 1 and group 2

Row	Gap value with the random algorithm (group 1)		Gap value with the sequence algorithm (group 2)	
	Average gap value	Average standard deviation	Average gap value	Average standard deviation
6	1.23	1.58	1.21	1.54
7	1.33	1.93	1.02	1.43
8	1.44	1.78	1.21	1.51
9	1.5	1.91	1	1.31
10	1.08	1.42	0.96	1.23
Aver-age	1.31	1.724	1.08	1.404

Results from both tables show that average gaps of each row when using the sequence algorithm (1.3 in Table 5.8 and 1.08 in

Table 5.9) to present influence factors are lower than using the random algorithm (1.43 in Table 5.8 and 1.31 in Table 5.9). These results also imply that the technique to present influence factors affects the appearance of anchoring and adjustment heuristics in decision making at a different level. The difference in gap value is increased when an evaluation proceeds in a longer period. The difference of average gap value between the sequence algorithm and the random algorithm from row 1 to row 5 is lower than from row 6 to row 10. One reason can be the ability to make a reasonable decision is lower in a longer period. At the beginning of the evaluation, the decision maker has the ability to make a potential decision by making a rational consideration. In the situation that the decision maker is fatigue from making a decision in a long period and the simple technique is applied to support decision making, the decision maker automatically applies that technique without any consideration. Using the initial value to be a reference point and adjusting the new value-based on this reference point is a simple technique that can reduce an effort to make a decision. If a complex technique, on the other hand, is applied in that situation, the decision maker will take more time to make a decision or avoid to make a decision.

Even if the difference gap values from both algorithms were not definitely difference, results from this experiment show an appearance of anchoring and adjustment heuristic when evaluating an influence value using the sequence algorithm in the scenario method. The decision maker refers and adjusts the current decision on the initial value from the previous decision, which can be seen in the sequence algorithm. Accuracy of the decision, therefore, depends on the preciseness of the initial information. Therefore, the decision maker should be aware of an influence of the initial information before making a decision. Another possibility is to make a decision based on different initial information to avoid concentrating on a piece of information.

5.5 Conclusion

Results from this chapter showed examples of heuristic decisions and biases in product development under different possible situations as proposed in Chapter 4. These results imply that heuristic decisions and biases can appear in the activity in product development such as selecting the product profile. Heuristic decisions, and biases can influence the decision maker no matters using or not using the design method to support the decision making. The reason is the structures and components in the method can lead the decision maker to use heuristic decisions. Therefore, resources of the heuristic decisions and biases do not only come from the decision maker but also come from the environment and different ways to present alternatives (called choice structure). However, these behaviors are not only represented by decision bias, but these behaviors can also be defined in terms of predictable decisions. Moreover, these behaviors usually happen when the decision maker is not aware of the influence of heuristic decisions. Investigating a method to avoid or reduce the decisions biases in different activities of product development is required in the further step.

6 Investigating and developing potential methods to handle decision biases in product development

Regarding the appearance of heuristic decisions and biases in activities of product development from the previous chapter, potential methods to handle these biases are then required. This chapter starts with investigating potential methods to control or handle decision making from different fields such as psychology and economics. Then those potential techniques are applied and developed based on decision characters in the product development process.

6.1 Potential methods to handle decision biases from other fields

As described in the literature review (Section 2.5), there are many de-biasing methods that can be used based on types of biases and decision situations. These methods were proposed to deal with different situations of biases without being classified in groups. This research, however, separates the de-biasing techniques based on the concept idea from Jack (Soll, Milkman & Payne, 2015) into two approaches regarding the resources of biases. These 2 approaches are 1) to influence the decision maker and 2) to modify the environment or choice structure.

6.1.1 De-biasing approach by influencing the decision maker

Example methods that related to this approach are providing a decision maker with knowledge, increased decision awareness, and encourages the decision maker to think broader. However, all of these methods aim to increase the decision maker’s knowledge by training system 1 thinking (fast thinking) and System 2 thinking (slow thinking). System 1 is trained to generate better intuitions from experience and memory. System 2 is trained to better control system 1 to be aware of biases in different situations. Another de-biasing technique is providing feedback to the decision maker, which leads the decision maker to think broader. Feedback can be social feedback or personal feedback.

6.1.2 De-biasing approach by modifying the environment or choice structure

A choice structure can be seen as a resource of decision bias and also can be used to de-bias decision biases. One famous method that is usually applied to control human behavior is the nudge method. The nudge method can persuade the decision maker to make a decision in an expected direction. The decision maker can have a response or no response to this action. Components in the nudge also include giving feedback as described in 6.1.1. Another type of de-biasing method is MINDSPACE, which has a similar concept as the nudge method but consists of different components as described in Section 2.5. Without applying the nudge or MINDSPACE method to modify the choice structure, the choice can be adjusted by changing the number and sequences of alternatives presented to the decision maker.

These 2 approaches, however, are applied to handle or control decision biases without any guidelines. People select methods to reduce decision biases based on their consideration. It is different from applying a nudge strategy to influence decision behavior; there are many frameworks that are used to describe types of a nudge from different fields.

Four frameworks from different fields in the literature (Section 2.5) are summarized in Figure 6.1.

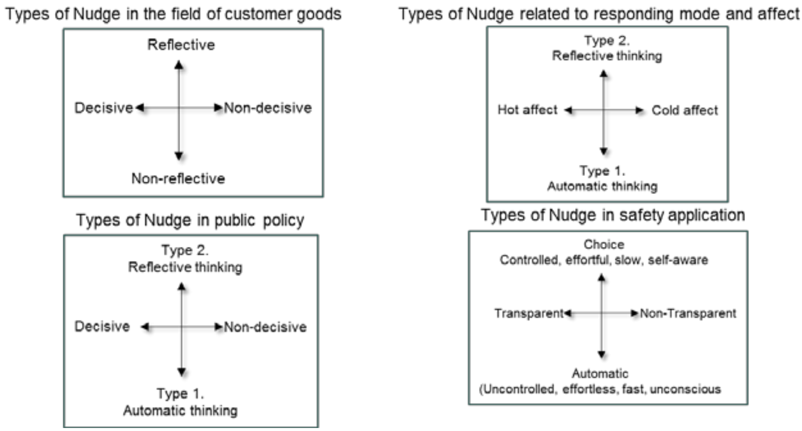


Figure 6.1: Frameworks to apply a nudge to handle decision behavior from different fields

Some criteria have a similar meaning but use a different name such as reflective vs non-reflective in the field of customer food and reflective thinking vs automatic thinking in the field of mode and affect. Most of them refer to techniques to response to decision making when encountering to some stimuli. Objectives to influence decision makers are also used in the framework.

However, criteria in each framework from different field vary on researcher's perspective and description. These framework cannot be directly applied to the framework for product development because decision situations are different and techniques in each framework focusing on a nudge. The satisfying solution can be described in decision situations in other fields but cannot be illustrated in product development. However, concept ideas for each criterion from these 4 frameworks are applied to design the framework of de-biasing technique in product development. This framework as shown in Figure 6.2 classifies types of de-biasing techniques into 4 types regarding direct-indirect to the decision makers and aware-unaware about the decision bias.

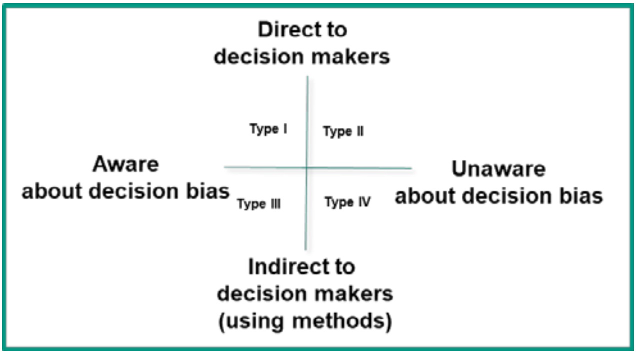


Figure 6.2: The framework to apply de-biasing techniques in product development

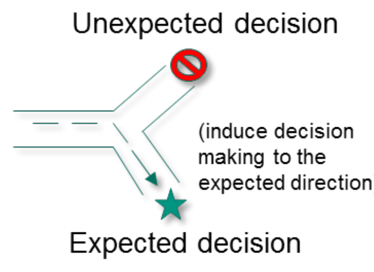
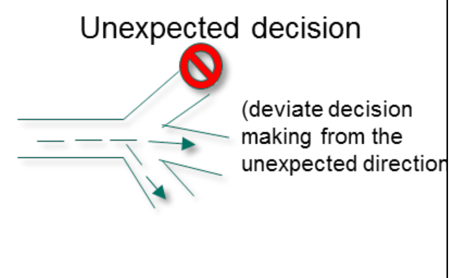
Aware and unaware about decisions bias are the first criteria for the framework in product development. The concept idea for this criterion is similar to the reflective and non-reflective thinking in other frameworks. However, reflective and non-reflective thinking refers to reflective thinking of general decision. Decision biases are not specified. Aware and unaware about decision biases are more specific than reflective and non-reflective thinking. Direct and indirect to the decision makers are the second criterion in this framework, which are different from other fields. This criterion separates types of de-biasing techniques based on the target of applying techniques. However, the target to apply de-biasing technique is not the main point for other fields to classify types of de-biasing technique. “Indirect to the decision makers” refers to applying de-biasing techniques to methods. This idea comes from the results in Section 4 and Section 5 that showed an appearance of heuristic decisions and biases even using design methods to make decisions. These methods are usually used to support the decisions in product development, which are different from other fields. Decisions in the frameworks from other fields are usually referred to decisions from their intuition and experiences without supporting techniques.

De-biasing techniques in other fields are, therefore, usually used to avoid the decision bias by pushing or guiding the decision maker to go in the correct direction. On the other hand, the de-biasing techniques in product development are usually used to avoid decision bias by pushing the decision maker away from the bias direction or letting them be aware of the bias direction. It is not necessary to avoid decision bias; it is important to be aware of it. The reason is the correct and good decisions can be defined and evaluated in other fields but not in product development. Decisions in product development cannot be defined and evaluated until the product is launched to the market, which sometimes requires many years.

The difference between the framework to apply de-biasing techniques in product development and the framework to apply nudge to handle decision behavior from other fields is shown in Table 6.1.

Table 6.1: The difference between the frameworks to apply nudge from different fields and the framework to apply de-biasing techniques

The frameworks to apply nudge from different fields (Figure 6.1)	**The framework to apply de-biasing techniques in product development (Figure 6.2)**
The correct decision has to be indicated before selecting the de-biasing technique. The framework is, therefore, used to lead decision making in the expected/predictable/correct way	The correct decision cannot be indicated. The framework is, therefore, used to avoid leading the decision in a predictable way.
Techniques are usually applied directly to the decision maker but required different system thinking (fast or slow thinking)	Techniques can be applied directly to the decision maker or to the supporting methods

<table>
<tr><th>The frameworks to apply nudge from different fields (Figure 6.1)</th><th>The framework to apply de-biasing techniques in product development (Figure 6.2)</th></tr>
<tr><td>
</td><td>
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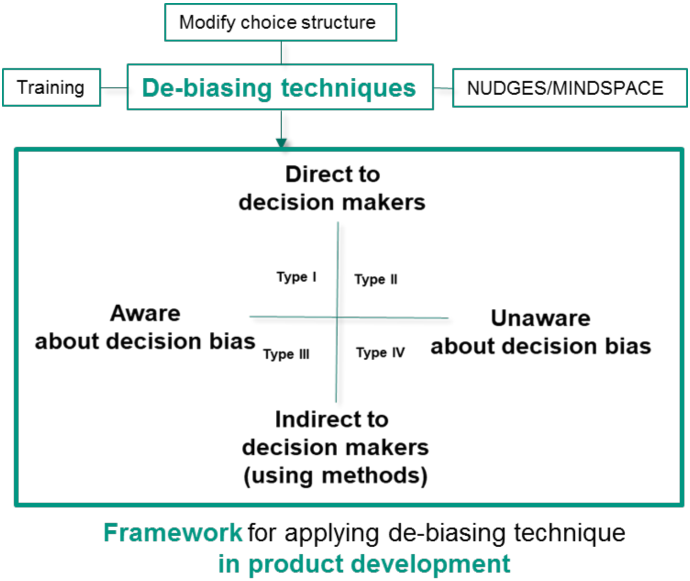
6.2 Integrating techniques to handle decision biases in the framework

De-biasing methods that were proposed in the literature review (Section 2.5) and summarized in Section 6.1 were implemented in the framework to apply the de-biasing technique in product development. De-biasing techniques are classified into 3 groups: training, modify choice structure, and NUDGES/MINDSPACE based on techniques to influence decision behavior. Techniques in each group are proposed and developed based on criteria from the framework in Figure 6.2, which possibly present into 4 types. Each type of de-biasing techniques regarding this framework and examples of de-biasing techniques for each type are shown in Figure 6.3.



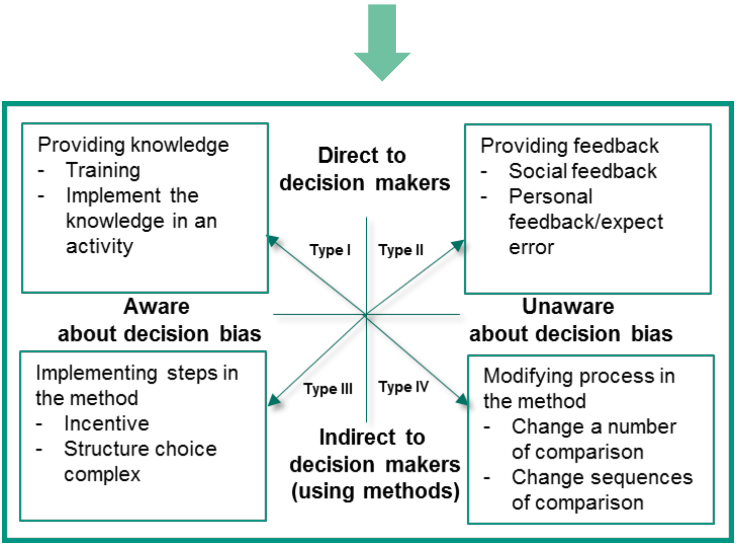


Figure 6.3: Integrating de-biasing techniques in the framework for applying the de-biasing technique in product development

De-biasing type I aims to provide the knowledge about heuristic decisions and biases to the decision makers to let them be aware of the influences of biases. Techniques in this type affect directly to the decision maker. This type of de-biasing techniques should be used before the decision is made or the project is started to improve the system 1 and system 2 thinking. This is suitable when decision biases cannot be defined in specific processes in product development. However, the level of achievement in de-biasing also depends on personal skill and awareness, which are difficult to be controlled.

De-biasing type II also affects directly the decision maker. Techniques in this type aim to remind the decision maker regarding his/her decision. Techniques in this type help the decision maker to rethink and review his/her decision, which is one method to evoke system 2 to make a decision. The decision maker is not required to be aware of heuristic decisions and biases. Techniques in this type are appropriated to the situation that requires fast response, which is easy to generate the decision bias. Feedback is an efficient technique to remind the decision maker to review his/her decision such as social feedback, customer feedback or marketing feedback.

De-biasing type III aims to reduce the bias caused by the method as mentioned in Section 4. Therefore, de-biasing techniques in this type are integrated into the method instead of affecting directly to the decision maker. Instead of inducing decisions to the expecting solution, techniques in this group deviate decisions from a trap in heuristic decisions and biases. The result after applying the de-biasing technique in the method is then compared to the result without the de-biasing technique. This type only helps the decision maker to analyze the different results from different processes of evaluation and understand the influence of biases on the results. The decision maker has a chance to accept or reject the result that is influenced by decision bias. In product development, results of decision making from the heuristic decisions and biases are sometimes more acceptable than results of decision making without heuristic decisions and biases. This point, therefore, leads to the de-biasing techniques in type III.

The last type of de-biasing techniques (De-biasing type IV) is also implemented in the method and not required the decision maker's awareness of heuristic decisions and biases. The technique in this type intends to help the decision maker to concentrate on the contents of alternatives rather than surrounding environments. There are many times that the solution in product development is selected because it is better than the other solutions not because of a good solution. The bias is caused by the way to present information and alternatives; therefore, de-biasing techniques in this type are also referred to as the way to present information. This type of de-biasing technique is appropriated to handle heuristic decisions and biases when prioritizing alternatives and selecting the final solution.

Some types of de-biasing techniques require tools or materials to support decision making; some types can be implemented directly to the available methods/processes in product development. De-biasing techniques regarding each type in the framework have been developed and evaluated based on activities in product development that are described in the next section.

6.3 Conclusion

Heuristic decisions and biases can be handled with different techniques based on the situations and objectives. Decision biases can be avoided by inducing the decision maker to select a good solution using the nudging technique and choice structure, which are the main techniques in many fields. However, this technique cannot be directly used in product development because the correct or good solutions cannot be defined. De-biasing techniques are, therefore, used to deviate the decision maker to go to the predictable decision. The framework for applying the de-biasing techniques in product development is then proposed by modifying concept ideas from different framework of applying nudging strategy from different fields. For example, reflective and non-reflective criteria from other frameworks are the basis idea for aware and unaware about decision biases. This framework separates de-biasing techniques into 4 types: providing knowledge, providing feedback, implementing steps in the method, and modifying the process in the method. These 4 types are separated based on direct-indirect to the decision makers and aware-unaware about the decision bias.

7 Developing and evaluating methods and materials to de-bias the heuristic decisions and biases in product development

After defining types of de-biasing techniques in the framework, exemplary tools and methods are developed and modified to handle the heuristic decisions and biases in different activities of product development. These tools and methods are classified based on the framework for applying de-biasing techniques in product development as shown in Figure 7.1.

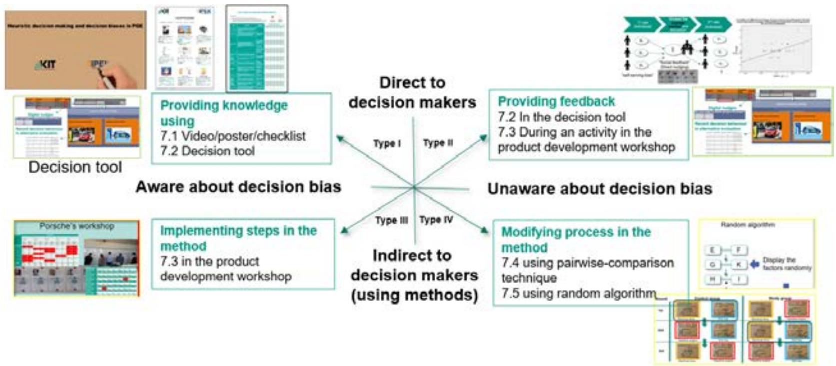


Figure 7.1: An overview of de-biasing tools and methods to handle heuristic decisions and biases based on the framework for applying the de-biasing technique in product development

7.1 Developing and evaluating the video, checklist and poster to transfer knowledge about heuristic decisions and biases to decision makers

The first group of de-biasing techniques is the technique to raise the decision makers' awareness about the heuristic decisions and biases by providing them the knowledge as shown in Figure 7.2.

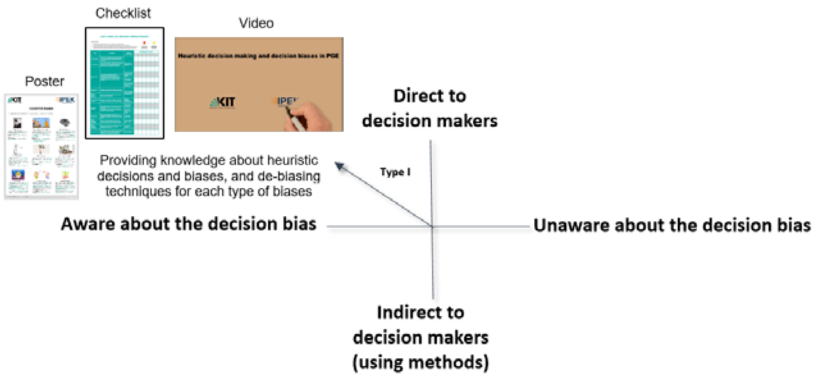


Figure 7.2: De-biasing technique type I

This technique is the fundamental technique for improving decision making in system 1 and system 2. There are 2 types of tools that are aimed to be developed to transfer the knowledge to the decision makers (An, 2020)[1].

The first tool is a video. This tool is attractive for learning something new because this tool can activate the decision makers' motivation by stimulating visual and auditory perceptions. This tool is the fundamental tool and the first step to improve the knowledge of decision makers. However, this tool is low effective to keep the knowledge in the long-term memory. Therefore, the information from the video can rarely be recognized and decided to apply in the real situation. It is also inconvenient for the decision makers to watch the video to get information during working time. Therefore, this tool aims only to influence a short term memory of the decision maker

[1] Co-supervisor of Master thesis

about heuristic decisions and biases and motivates the decision maker to be aware of them during making decision.

Thus, the second tool is the poster providing information and knowledge about the heuristic decisions and biases that could affect the decision makers during the working time. When people encounter the same information a long time later, their brains will remember that information automatically. The poster hung in the workplace develops a short-term memory, cultivating knowledge on a long-term basis from the video.

Posters are separated into 2 types:

1) The poster that provides only information or knowledge
2) The poster that requires an action from the participants in the checklist form.

Processes to develop these tools and contents in the tool are explained in the next section. These tools are evaluated by implementing in the Live Lab with students and the company with engineers for making an evaluation.

7.1.1 Developing the video, poster, and checklist to transfer knowledge about heuristic decisions and biases

Basic information or knowledge that are integrated into these 3 materials are

1) Different types of heuristic decisions and biases
2) Descriptions of each type
3) Examples of heuristic decisions and biases in product development
4) De-biasing methods that can be applied to avoid each heuristic decision and bias.

After gathering and classifying this information from the literature and experiments, the video, the poster, and the checklist are developed.

Video

As described in the previous part, the video is aimed to increase the participants' motivation to get knowledge about heuristic decisions and biases. In the beginning, the knowledge about heuristic decisions and biases are introduced to the participants. Information in the video is aimed to increase motivation to know and understand more about them to improve decision making. People who are aware of the advantages of information or knowledge have more chances to remember the contents that are provided to them than people who have no motivation to learn something new or be unaware of the advantages of information and knowledge. The length of this video is around 10 minutes. Contents in the video and video's storyboard are explained in the following step:

Step 1: Introduce an illumination picture that can lead the cognitive bias caused by the heuristic decision

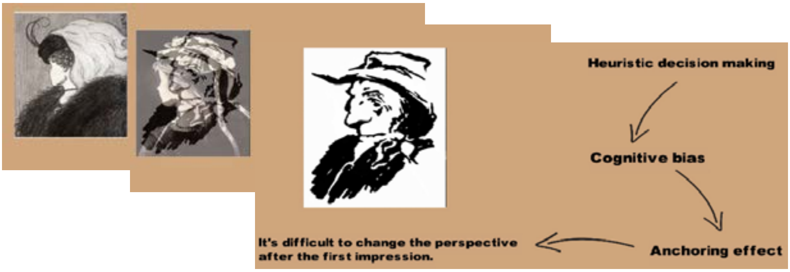


Figure 7.3: Introduce an illumination picture to link to the heuristic decision

Step 2: Explain different types of decision making, which are statistic, rational, and heuristic

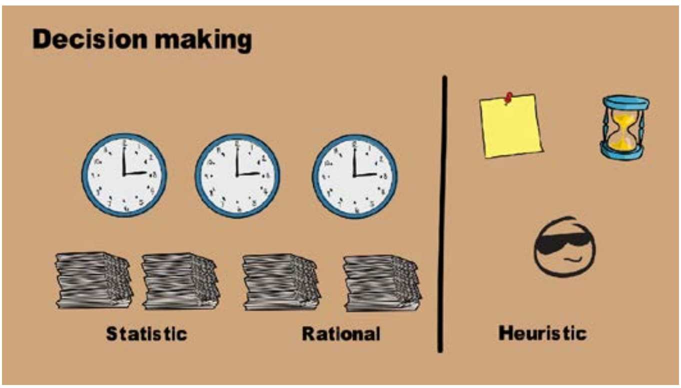


Figure 7.4: Different types of decision making

Step 3: Explain the relationship of heuristic decision and cognitive bias and provide examples of six heuristic decisions and biases. These 6 heuristic decisions and biases are anchoring heuristic, representativeness heuristic, availability heuristic, confirmation bias, messenger bias, and overconfidence bias. Anchoring heuristic, representativeness heuristic and availability heuristic are the fundamental heuristics for the study of heuristic decisions and biases. Other heuristics and biases are selected based on the study in Chapter 4 and Chapter 5. Three resources that can influence the decisions are information, other persons, and the decision maker, which can be present by confirmation bias, messenger bias, and overconfidence effect.

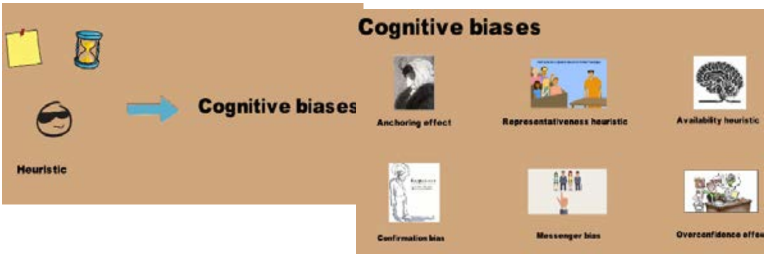


Figure 7.5: The relationship of heuristic decision and cognitive biases with 6 types of heuristic decisions and biases

Step 4: Explain each type of heuristic decisions and biases by providing an example from the general field, and then an example in product development. Figure 7.6 shows an example of an explanation in one heuristic decision

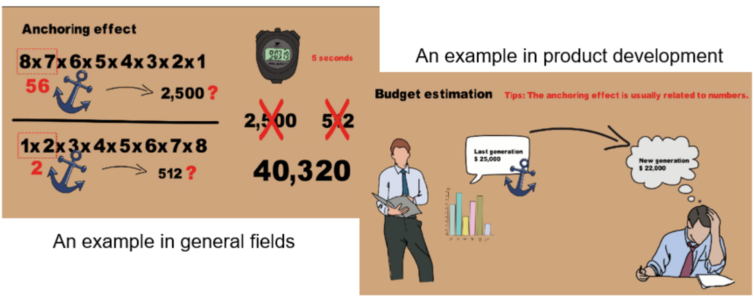


Figure 7.6: An explanation of heuristic decisions and biases using an example in the general field and an example in product development

Step 5: providing examples of de-biasing techniques for each type of heuristic decision and bias. These examples are from the general situation and from the situation in product development.

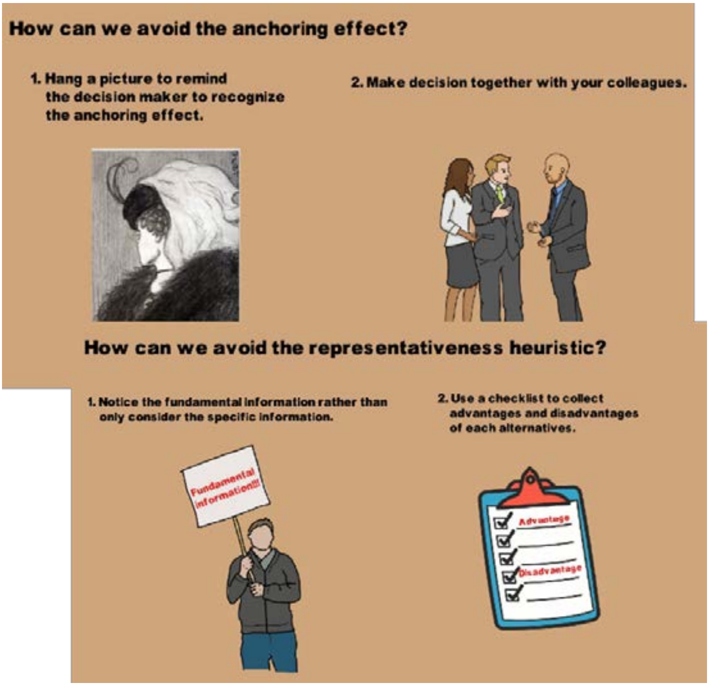


Figure 7.7: Examples of de-biasing techniques for each type of heuristic decisions and biases

Poster and Checklist

A poster is usually used to transfer knowledge or information to people. This material makes a quick, immediate visual impression on potential target groups. People can see the poster and get information from it as long as the poster is put up on the working place. The poster in Figure 7.8 is developed based on an idea to remind the decision maker about the contents in the video and induce the decision maker to be aware of heuristic decisions and biases in the daily activity of product development. This material will help to remind people without consuming time or effort. Contents in the poster focus on types, explanations, and examples of each heuristic decision and biases with related figures. Moreover, three types of heuristic decisions and biases that were not in the video from the beginning experiment were implemented in the poster to evaluate the potential of the poster to provide new information. Even though the poster is aimed to remind decision makers the information in the video, we also would like to investigate the ability of poster to transfer the information. These 3 types are 1) overchoice, 2) framing effect and 3) self-serving bias, which are selected based on a possibility of appearance during developing a product in the project.

A checklist is a part of the poster that is aimed to remind the decision maker of the contents in the video and induce the decision maker to be aware of heuristic decisions and biases in general activities in product development. However, the checklist needs action from the participants to recheck their decision behaviors. This material intends to provide knowledge and rechecks from the feedback by participants, which is different from the poster that only provides knowledge or information without requiring a respondent from the participants. The result of this material will be compared to the result from the poster to investigate a better method to transfer the knowledge during product development, which should be available in the working station. Figure 7.9 shows the poster that will be applied in an experiment.

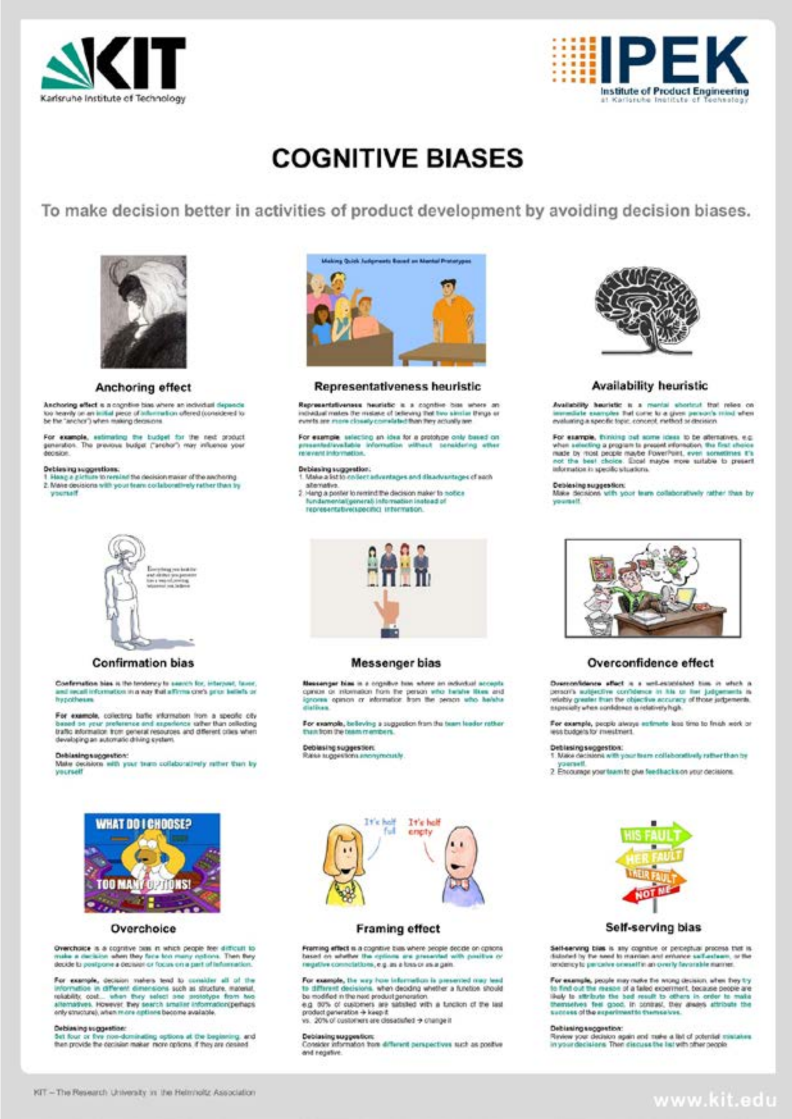


Figure 7.8: The poster to transfer knowledge about heuristic decisions and biases, and de-biasing techniques for each decision bias

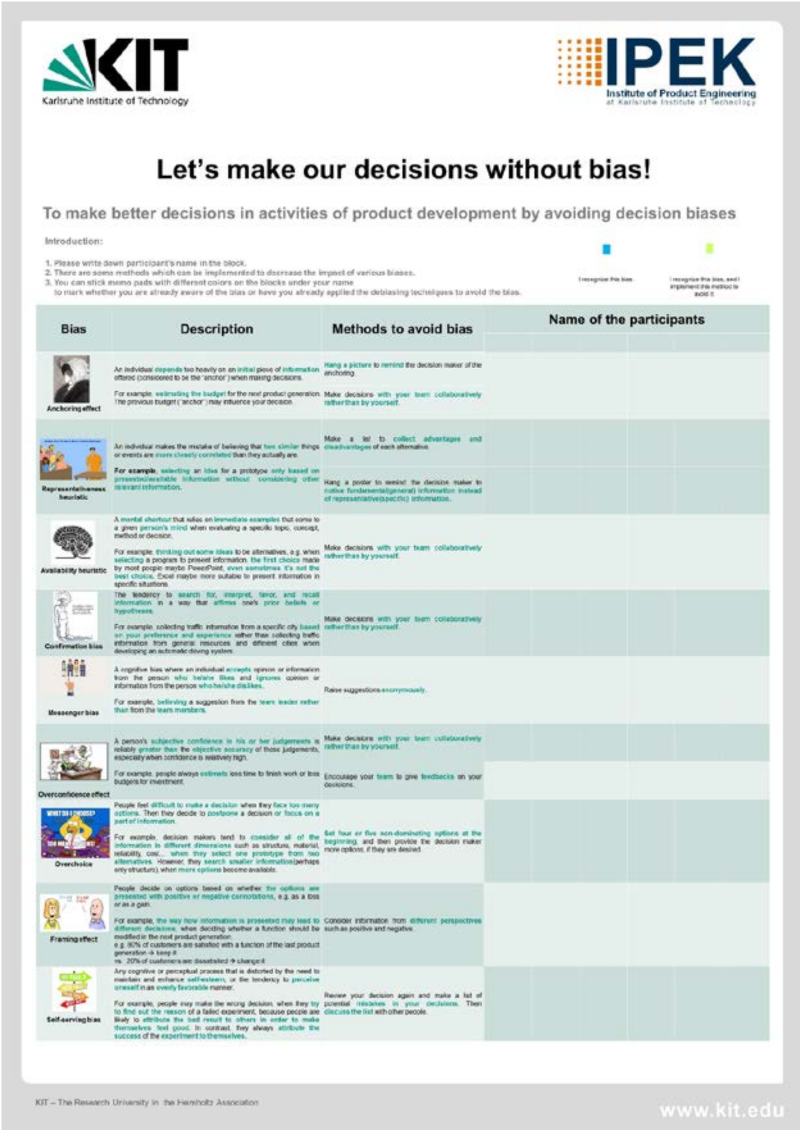


Figure 7.9: The checklist to transfer knowledge about heuristic decisions and biases, and de-biasing techniques for each decision bias

7.1.2 Design experiments to evaluate the performance of each tool to transfer the knowledge about heuristic decisions and biases in different situations

The experiment to evaluate the performance of each tool to transfer information about heuristic decisions and biases to reduce the decision biases was done with 2 groups of participants. The first group of participants is the students in the IP project that is the Live Lab for product development (Albers, Bursac et al., 2018). Students in this project have to develop a real product, which is assigned by the company. The students are separated into 7 groups, and members in each group are in charge of different roles. Details in this project have been described in Section 4.3.1. The second group of participants is a group of engineers in one company. The number of participants in the first group and the second group are 35 and 10, respectively. Then results from both groups are compared to find the efficiency of de-biasing techniques by transferring knowledge about heuristic decisions and biases to the decision makers using different tools. Processes of experiments with the students in IP project and the engineers in one company are shown in Figure 7.10 and 7.11, consequently.

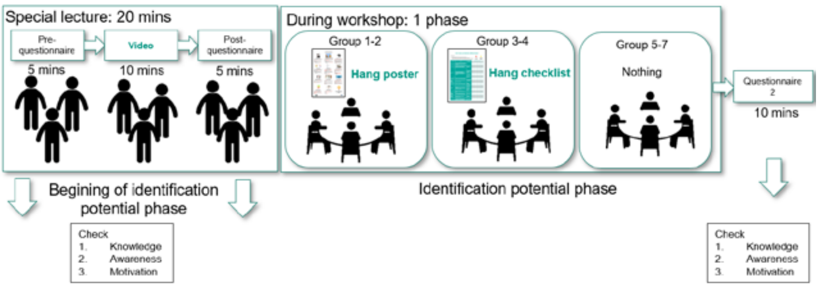


Figure 7.10: Processes of experiment with the students in the IP project

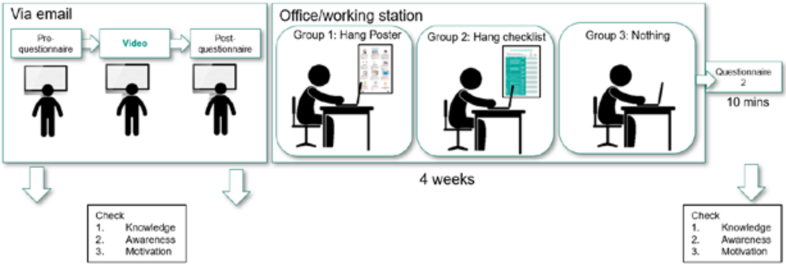


Figure 7.11: Processes of experiment with the engineers in the company

The experiment with the students in the IP project was done in the potential identification phase. This phase aims to find the product profile based on the customer's requirement and the company's requirement. At the beginning of this phase, all students in this project were invited to participate in the lecture. However, only 30 students could participate in this lecture. The students were asked to do the pre-questionnaire as shown in Figure 7.12 to evaluate their fundamental knowledge about the heuristic decisions, which took around 5 minutes to finish the questionnaire. Then the video, as described in the previous section, was introduced and shown to all students. After that, the students were asked to answer the questions in the post-questionnaire as shown in Figure 7.13.

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Pre-questionnaire

1. Have you ever heard of heuristic decision?
   A. yes B. no

2. How many cognitive biases do you know?
   A. 0-2 B. 3-5 C. 6-8 D. >=8

3. Imagine you are the manager of a company which prepares to develop a new product generation. You should estimate the budget of the new product generation at the beginning. Normally, the budget to develop a new product generation is €25,000, which is sometimes too much and sometimes too little to develop a new product generation in a project. What do you think the budget of this new product generation should be?
   A. The budget should still be €25,000, because many old projects also have this amount of budget.
   B. I have to approximate the budget based on this project. I can't answer now how much the budget should be.
   C. Others:

4. Would do you like to learn the knowledge about heuristic decision and decision biases?
   A. Yes B. No C. I'm not sure.

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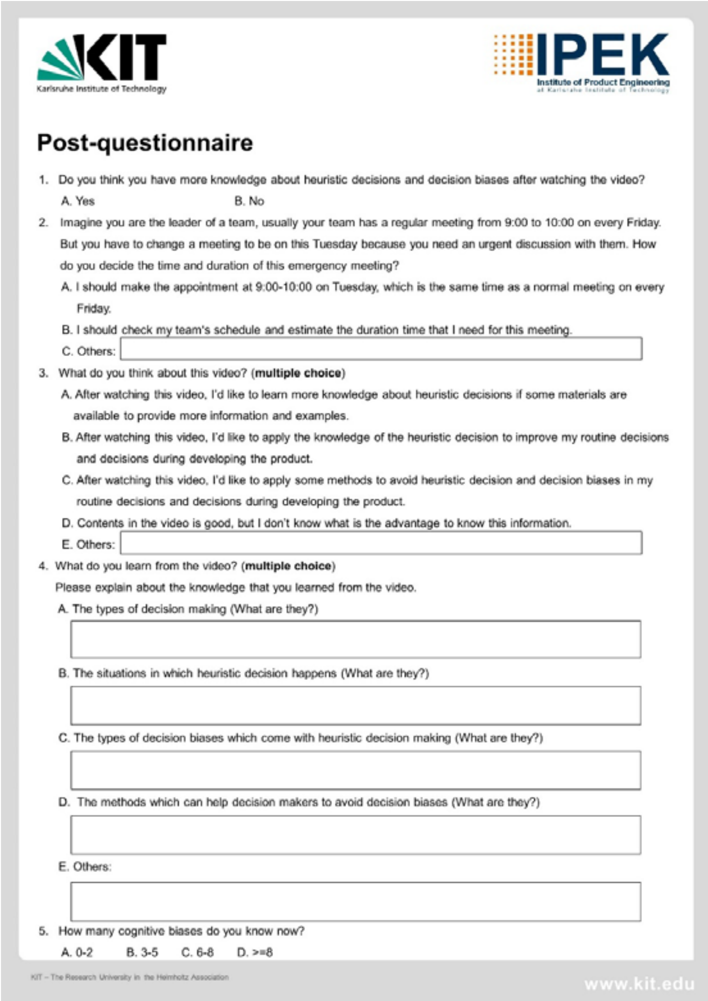
Figure 7.12: Pre-questionnaire



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Post-questionnaire

1. Do you think you have more knowledge about heuristic decisions and decision biases after watching the video?
   A. Yes B. No
2. Imagine you are the leader of a team, usually your team has a regular meeting from 9:00 to 10:00 on every Friday. But you have to change a meeting to be on this Tuesday because you need an urgent discussion with them. How do you decide the time and duration of this emergency meeting?
   A. I should make the appointment at 9:00-10:00 on Tuesday, which is the same time as a normal meeting on every Friday.
   B. I should check my team's schedule and estimate the duration time that I need for this meeting.
   C. Others:
3. What do you think about this video? (**multiple choice**)
   A. After watching this video, I'd like to learn more knowledge about heuristic decisions if some materials are available to provide more information and examples.
   B. After watching this video, I'd like to apply the knowledge of the heuristic decision to improve my routine decisions and decisions during developing the product.
   C. After watching this video, I'd like to apply some methods to avoid heuristic decision and decision biases in my routine decisions and decisions during developing the product.
   D. Contents in the video is good, but I don't know what is the advantage to know this information.
   E. Others:
4. What do you learn from the video? (**multiple choice**)
   Please explain about the knowledge that you learned from the video.
   A. The types of decision making (What are they?)
   B. The situations in which heuristic decision happens (What are they?)
   C. The types of decision biases which come with heuristic decision making (What are they?)
   D. The methods which can help decision makers to avoid decision biases (What are they?)
   E. Others:
5. How many cognitive biases do you know now?
   A. 0-2 B. 3-5 C. 6-8 D. >=8

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Figure 7.13: Post-questionnaire

After the lecture, the poster was assigned to students group 1 and group 2. The checklist was assigned to students group 3 and group 4. Only 3 groups from group 5 to group 7 got nothing, which were used as the control group. At the end of the phase (around 4 weeks since the beginning of the lecture), the students were asked to answer the questionnaire in Figure 7.14 to evaluate the efficiency of the poster and checklist.

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Questionnaire in workshop

1. Which material has been offered to you in your workplace?
   A. Poster B. Checklist C. No material
2. After applying this material, did you **get more knowledge** about heuristic decision and decision bias?
   A. Yes, I got some new knowledge from this material, and I still remember some contents of the video.
   B. No, I didn't get any new knowledge from this material, but I remember some contents of the video.
   C. No, I didn't get any new knowledge from this material, and I can't remember the contents of the video.
3. What do you think about this material? (**multiple choice**)
   A. After applying this material, I still would like to **learn more knowledge** about heuristic.
   B. After applying this material, I'd like to apply the knowledge about heuristic to **improve my routine decisions**.
   C. After applying this material, I'd like to **apply some methods to avoid heuristic decision and decision biases**.
   D. Contents in this material is good, but I don't know what is the advantage to know this information.
4. Can you **be aware of heuristic decision and decision bias** during this phase?
   A. Yes, I usually considered heuristic decision and try to be careful when making decisions.
   B. Yes, but I didn't usually consider heuristic decision nor try to be careful when making decisions.
   C. No, I never thought about heuristic decision and decision biases when making decisions.
5. During this phase, did you try to make decision carefully?
   A. Yes, I tried to make **more than 75%** of decisions carefully.
   B. Yes, I tried to make **50%-75%** of decisions carefully.
   C. Yes, I tried to make **less than 50%** of decisions carefully.
   D. No, I have no interest in making decision carefully.
6. How many cognitive biases do you know now? (**Please write them down**)
   A. 0-2 B. 3-5 C. 6-8 D. >8
7. Please write down **all methods to avoid decision biases which you know**.
8. Have you ever noticed and applied other group's material?
   A. Yes B. No
9. **Please give some feedbacks on these materials.**
   Poster:
   Checklist:
   Video:

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Figure 7.14: Questionnaire after applying the poster and checklist in the experiment

The second group of participants consisted of 14 engineers who are working in the department of product development in one company. Participants from this group have experiences in product development between one to five years. Participants in this group, therefore have more experience in product development more than the first group. The experiment was done by sending the email and having short interviews with them. At the beginning of the experiment, the Pre-questionnaire was sent to all participants via email. Then the link to open the video, which is the same video that was shown to the first group of participants, was sent to all participants. After watching the video, they answered the post-questionnaire to evaluate their improvement of knowledge. These 14 engineers were then separated into 3 groups. 5 engineers in the first group got the poster to remind them of their knowledge from the video and some extra information. The 5 engineers in the second group got the checklist that was used in the same way as the poster. The other 4 engineers, were defined as a control group, got nothing. All materials were printed and put up on the wall at the personal working station for 4 weeks. In the end, the questionnaire in Figure 7.14 was sent to all engineers via email and short interviews were conducted again.

7.1.3 Evaluating the results of the performance of each tool to transfer the knowledge about heuristic decision and biases in different situations

After making the experiments, one result in the pre-questionnaire and two results in the post-questionnaire from the students were not completed. Therefore, only results from 29 students in the pre-questionnaire, 28 students in the post-questionnaire, and 14 engineers in both questionnaires were used to analyze the result of transferring knowledge about heuristic decisions using the video.

The first group of results aims to evaluate the performance of the video to transfer information about heuristic decisions and biases to students and engineers. Therefore, results from the pre-questionnaire and the post-questionnaire were analyzed at the first step. Level of knowledge before and after watching was investigated from question number 1 and 2 in the pre-questionnaire, and from question number 1, 4, and 5 in the post-questionnaire. Results from the first question from students and engineers were shown in Figure 7.15, which described that basic knowledge about the heuristic decisions and biases before watching the video. A changing of knowledge after watching the video was evaluated using the question number 1 in the post-questionnaire with yes-no answer. If the participant select “Yes” in this question, the interpretation will be “increasing”. Otherwise, the interpretation will be “stable”. This result is shown in Figure 7.16.

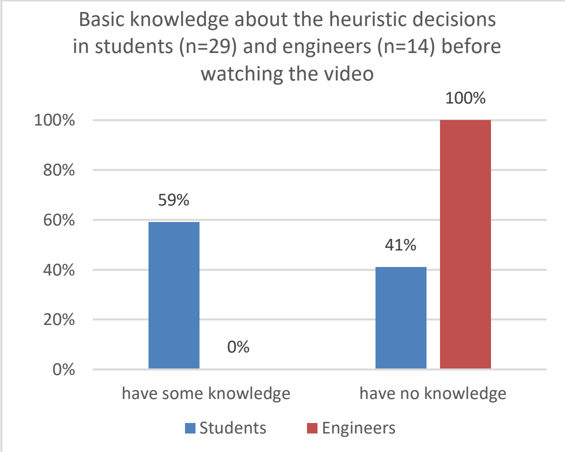


Figure 7.15: Results of basic knowledge from students and engineers before watching the video

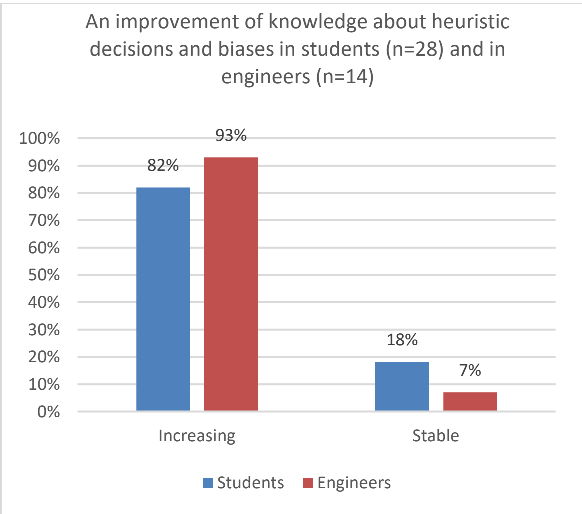


Figure 7.16: Results of an improvement of the knowledge about the heuristic decisions after watching the video

Results from Figure 7.15 and 7.16 show the different fundamental knowledge but a similar improvement of knowledge about the heuristic decision between both groups. Most of the students have some basic knowledge about heuristic decisions, which is different from the engineers that have no knowledge about it. One possible reason is some students have participated in the lectures about heuristic decisions. However, both groups, especially the engineering group, have more knowledge about heuristic decisions after watching the video. This conclusion is supported by the results from question number 2 in the pre-questionnaire and number 5 in the post-questionnaire, which shows the number of heuristics that participants know. Results from the students and the engineers are shown in Figure 7.17 and Figure 7.18.

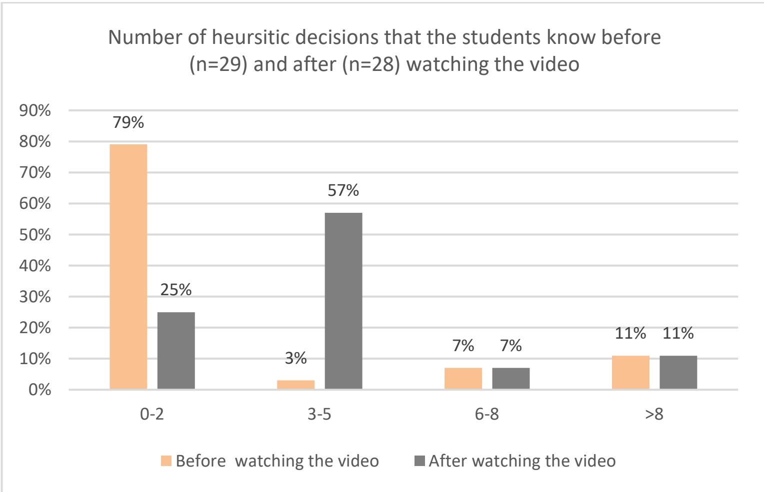


Figure 7.17: Number of heuristic decisions that the students know before and after watching the video

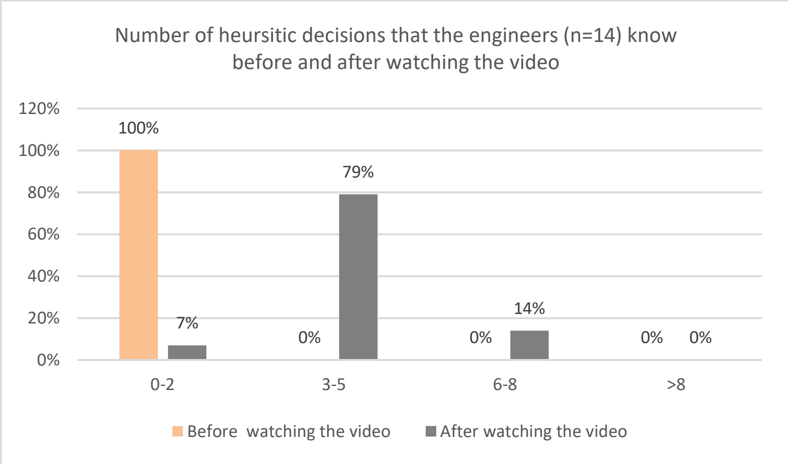
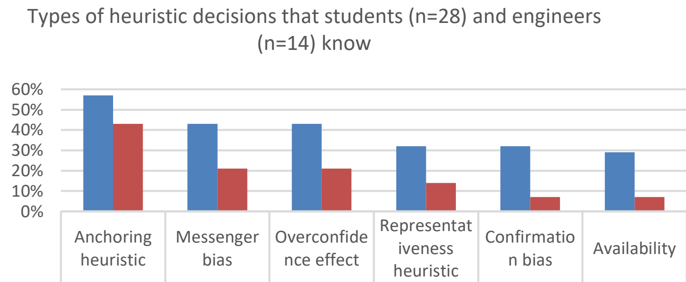


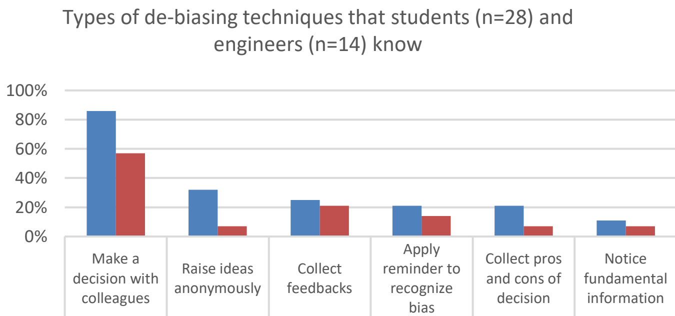
Figure 7.18: Number of heuristic decisions that the engineers know before and after watching the video

Most of students and engineers knew around 0-2 types of heuristic decisions before watching the video, After watching the video, most of them know around 3-5 types of heuristic decisions in average, which show an improvement of knowledge in both groups. These results imply that video can help decision makers to have more knowledge about heuristic decisions in both groups of participants. Moreover, results from question number 4.C and 4.D show types of knowledge that participants usually remember regarding types of heuristic decisions and de-biasing techniques. Figure 7.19 and Figure 7.20 show types of heuristic decisions and de-biasing techniques that students and engineers can remember, respectively.



	Anchoring heuristic	Messenger bias	Overconfide nce effect	Representat iveness heuristic	Confirmatio n bias	Availability
Students	57%	43%	43%	32%	32%	29%
Engineers	43%	21%	21%	14%	7%	7%

Figure 7.19: Types of heuristic decision that students and engineers know



	Make a decision with colleagues	Raise ideas anonymously	Collect feedbacks	Apply reminder to recognize bias	Collect pros and cons of decision	Notice fundamental information
Students	86%	32%	25%	21%	21%	11%
Engineers	57%	7%	21%	14%	7%	7%

Figure 7.20: Types of de-biasing techniques that students and engineers know

Anchoring heuristic is the most popular heuristic that participants from both groups can remember with 57% from students and 43% from engineers. One reason can be this type of heuristic was presented at the beginning in the video and illustrated in the first sequence of explanation. Therefore, participants can remember this heuristic easier than other heuristics. Confirmation bias and availability, on the other hand, are difficult for participants to remember. The examples are possibly not obviously seen in the real situation. However, the order of heuristic decisions and biases that participants from both groups can remember are similar. For the de-biasing techniques, making a decision with colleagues is the easiest method that participants from both groups can remember. It is a simple method that is usually used to exchange information and opinion in a real situation. Moreover, this technique was referred to many times in the video because this technique can be used to avoid different types of biases such as anchoring heuristic and the availability heuristic.

Other de-biasing techniques have quite similar trends to be remembered from both groups. Only raising ideas anonymously is different. Students remember this method better than engineers. This result can imply that students accustomed to present the idea and make a discussion at the same time during the meeting, which usually requires an explanation from the idea owner. Only a small number of ideas are presented and discussed in the meeting. It is not necessary to know the person who creates the idea until requiring a discussion about that idea.

Questions number 3 in the pre-questionnaire and number 2 in the post-questionnaire are used to evaluate the decision awareness about heuristic decisions when making a decision in a task. Anchoring bias was applied in these 2 tasks in pre- and post-questionnaire. If the participants select the solution with the specific number that is shown in the explanation (choice A in both questionnaires), the participants seem to be biased caused by anchoring bias. A description of the tasks actually cannot be used to make a decision; more information is required to make a suitable decision. Therefore, the number that is shown in the explanation is a trap from anchoring heuristic. The results from pre- and post-questionnaire in the student group and the engineering group are shown in Figure 7.21 and Figure 7.22, consequently.

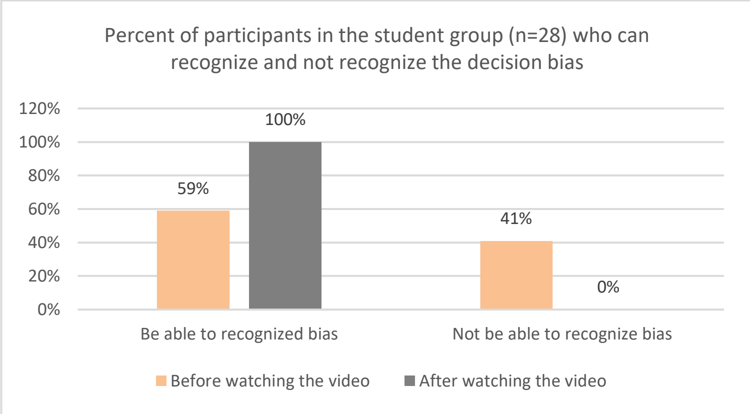


Figure 7.21: The result of decision awareness about the heuristic decision and bias before and after watching the video in the student group

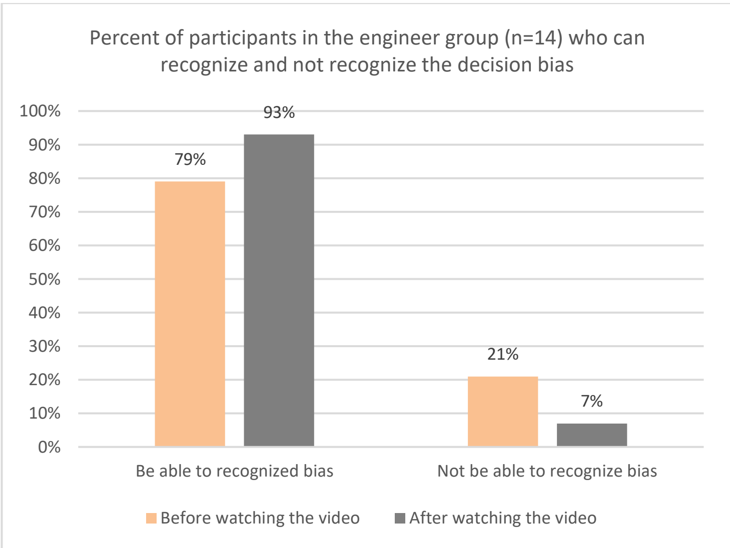


Figure 7.22: The result of decision awareness about the heuristic decision and bias before and after watching the video in the engineering group

Before watching the video, 59% and 79% of participants from the student and engineering groups could make un-biased decisions. Participants in the engineering group seemed to have more ability to make a rational decision. However, the influence of decision bias was reduced when the participants watched the video- increasing the number of participants who could recognize bias to be 100% of participants from the student group and 93% of participants from the engineering group. Results from both groups of participants confirmed the performance of video transferred knowledge of heuristic decisions and biases increasing the participant's awareness making decisions.

The last video evaluation on information transfer of heuristic decisions and biases to avoid decision biases was about motivation. The main objective of material was to motivate the decision makers to be aware of heuristic decisions and biases during making decisions. One problem that people experience in the trap of heuristic decisions, are that they have no knowledge or awareness of heuristic decisions and biases. This video, therefore, aims to increase the motivation to learn about the influence of heuristic decisions and biases and apply the knowledge in the routine activities and during developing a new product. This evaluation was done based on question number 4 in the pre-questionnaire and number 3 in the post-questionnaire. Figure 7.23 and Figure 7.24 show the result from the student group and the engineering group, respectively.

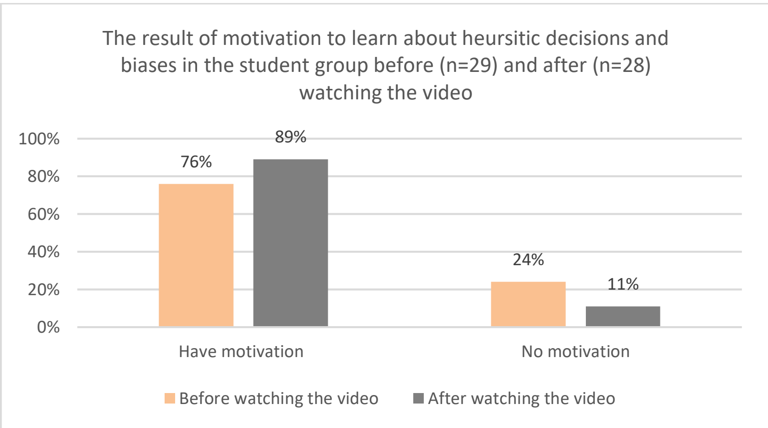


Figure 7.23: Efficiency of video to motivate participants in the student group to learn about the heuristic decisions and biases

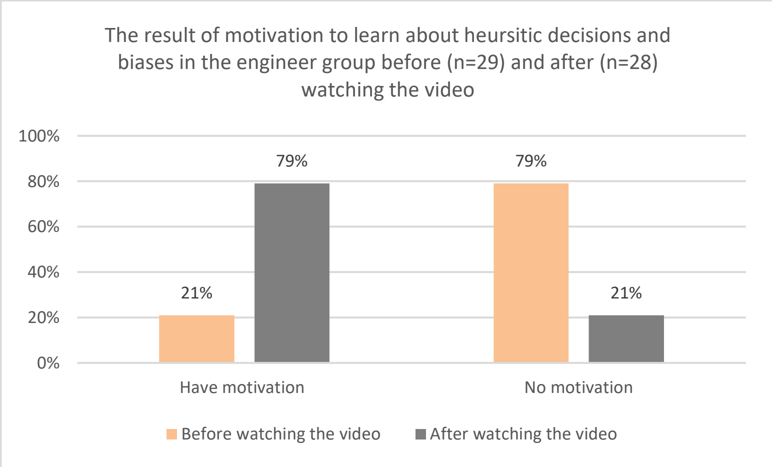


Figure 7.24: An efficient of video to motivate participants in the engineering group to learn about the heuristic decisions and biases

From the results, students had a lot of motivation to learn about heuristic decisions and biases, which is different from the motivation in the engineering group. One possible reason can be the students are in the stage of learning something new. Engineers are, on the other hand, in the stage to achieve their work as soon as possible. However, the video can motivate participants in both groups, especially the engineering group to learn more about heuristic decisions and biases. These motivations are separated into 3 levels:

1) Learn to have more knowledge
2) Learn to improve decision making by being aware of decision bias during making a decision,
3) Gain more knowledge to be possibly aware of decision bias and possible to avoid the bias.

For the students, 46% of participants aim to gain more knowledge and possibly be aware of the decision bias and avoid this bias. The motivation to gain more knowledge verses to improve decision making is equal with 25% of participants in the student group. The result from the engineering group has a few differences from the result of the student group. 43% of participants in the engineering group aimed to learn more about heuristic decisions and biases striving for awareness and management of them.

21% of the participants simply wished to gain more knowledge to improve their decision-making skills. These results show an efficiency of video to transfer knowledge about heuristic decisions to increase knowledge and improve an ability to make decisions without the influence of heuristic decisions and biases in the short term. The material, that is suitable to transfer knowledge in the long term such as poster and checklist, is then evaluated.

The second group of results is used to investigate and evaluate the performance of posters, checklist, and video during the working process. This evaluation based on the results from the last questionnaire in Figure 7.14. Three main topics are analyzed to find the efficiency of the material to remind the decision makers about the previous knowledge by retransferring the knowledge in a long term, which are 1) knowledge, 2) awareness and application, and 3) motivation. After analyzing the results in the student group, only 7 answers from the poster material, 8 answers from the checklist material and 7 answers from the control group and for no material were analyzed. All results from the participants in the company are completed, which separated into 5 answers from the poster material, 5 answers from the checklist material, and 4 answers from the control group who got nothing.

A performance of retransferring the knowledge when applying the poster and the checklist to transfer information comes from the result in question 2. Results from question 2 show an improvement of knowledge regarding different materials. If the participant selects the first answer that is the participant got new knowledge after using the material and still remember some contents in the video, the interpretation of performance of retransferring the knowledge will be “Increase”. If the participant selects the second answer that is the participant does not get new knowledge after using the material, but still remember some contents in the video, the interpretation of performance of retransferring the knowledge will be “Stable”. The other selection is the participant does not get new knowledge from the material and cannot remember contents in video. This selection will be interpreted to be “Decrease”. Results in Figure 7.25in the student group and Figure 7.26 in the engineering group also comes from the direct question that was evaluated by the participants.

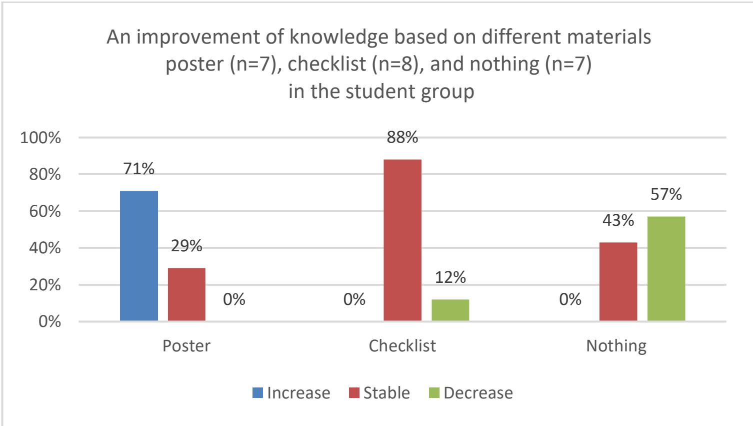


Figure 7.25: Results of knowledge improvement in the student group

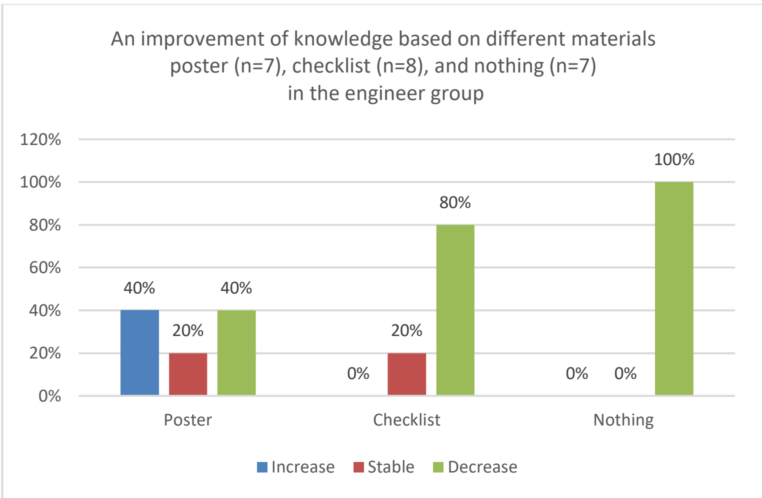


Figure 7.26: Results of knowledge improvement in the engineering group

Results from the student group showed that the student's knowledge is increasing 71%, stable 29%, and not decreasing when using the poster to transfer, retransfer and remind knowledge about heuristic decisions and biases, and de-biasing methods. 88% of students who got the checklist have no knowledge improvement, and the rest of the participants lose some knowledge. Students who got nothing are worse than other groups. Fifty seven percent of them lose some knowledge from the video; 43% of participants felt that their knowledge is stable. These results are quite similar to the results of the engineering group. Only 40% of participants in the poster group who felt that their knowledge is increasing. Twenty percent of them felt no improvement. However, there is 40% of participants in the poster group who has lower knowledge about heuristic decisions and biases. Results from the participants who use a checklist and no material seem to be similar. 80% of the participants in the checklist group and 100% of participants in the control group have lower knowledge about heuristic decisions and biases.

From these results, the poster is the most suitable material to remind the decision makers about the previous knowledge in the long term. People cannot remember all information in the video; therefore, the performance of the video is suitable for transfer the knowledge in a short term memory. The checklist seems to work well in the student group to brush them up on prior knowledge but is not suitable for the engineering group because the engineering group does not want to have and do extra work. These results can be confirmed by the number of heuristic decisions that the participants can remember, which showed in Figure 7.27 from the student group and 7.28 from the engineering group when using different materials to transfer, retransfer, and remind knowledge.

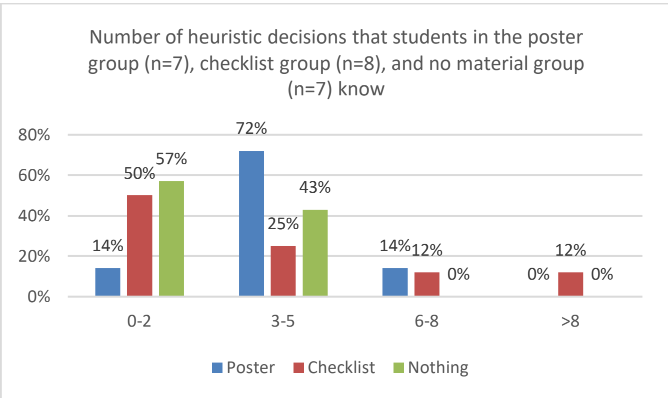


Figure 7.27: Number of heuristic decisions that students from different groups know

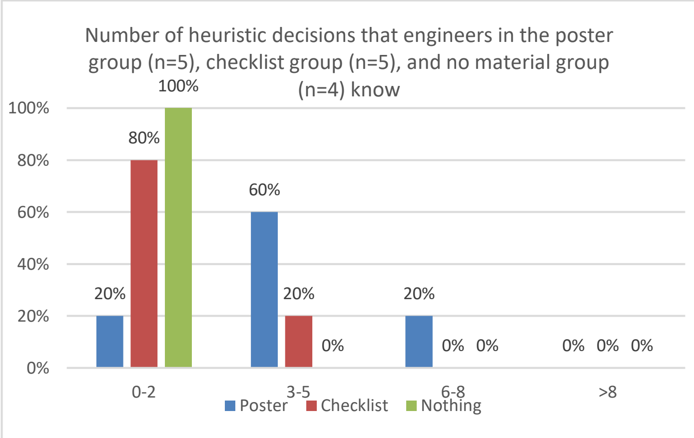


Figure 7.28: Number of heuristic decisions that engineers from different groups know

Based on the results in Figure 7.27 and 7.28, participants know 0-5 types of heuristic decisions and biases. Participants who got the poster tend to remember types of heuristic decisions and biases better than a checklist and no material. This result can imply that a suitable number to transfer knowledge about heuristic decisions and biases using poster should be lower than 6 types of heuristics. 43% of participants in the poster group can remember about the anchoring heuristic, messenger bias, and availability heuristic. In the engineering group, 60% of participants in the poster group can remember confirmation bias, messenger bias, overchoice, and self-serving bias. Knowledge from the students and engineers in the other groups cannot be evaluated. These results also show the different rankings of the heuristic type that students and engineers remember after watching the video. Participants who got the poster material can remembers types of heuristics more than participants who got other materials. Moreover, some information did not present in the video such as overchoice heuristic. That means some parts of memory come from the knowledge from the poster. De-biasing techniques that participants in the student group usually remember is to make a decision with a colleague. This technique can also be remembered in the engineering group. Moreover, collections of feedback and pros and cons of the decision were illustrated in the questionnaire. Even though the overall results from poster and checklist materials do not show high efficient to transfer or remind decision makers of the knowledge, it is better than no reminder material information at all.

Another result aims to evaluate the level of decision awareness. This evaluation comes from the results in Question 4 in the questionnaire in workshop (Figure 7.14). The level of awareness about heuristic decisions and biases are defined into 3 levels;

- Level 1: Cannot recognize heuristic decisions and biases
- Level 2: Can only recognize heuristic decisions and biases, but did not try to make decisions carefully
- Level 3: Can recognize heuristic decisions and biases, and try to make decisions carefully such as finding and applying a de-biasing technique to decision making.

Results from Questions 4 in Figure 7.14, are, then interpreted to these 3 levels. Participants will be defined in the first level when they selected the answer C in the question that is the participant never thought about heuristic decision and decision biases when making decisions. The second level represents the a group of participants who selected the answer B in the question that is the participant is aware of heuristic decisions and biases but did not usually consider nor try to careful of it when making a decision. Participants are classified to have an awareness in Level 3 when they selected the answer A in the question that is they are aware and considered about heuristic decisions and biases and try to make decisions carefully. Results of decision awareness of heuristic decisions and biases in the student group and the engineering group are shown in Figure 7.29 and 7.30, respectively.

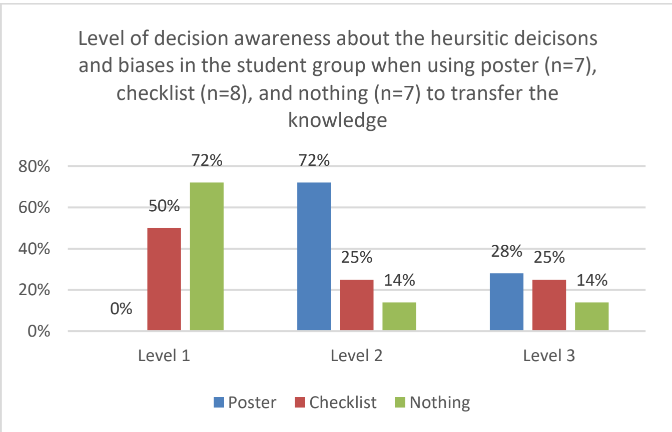


Figure 7.29: Level of decision awareness in the student group who used different materials to transfer knowledge

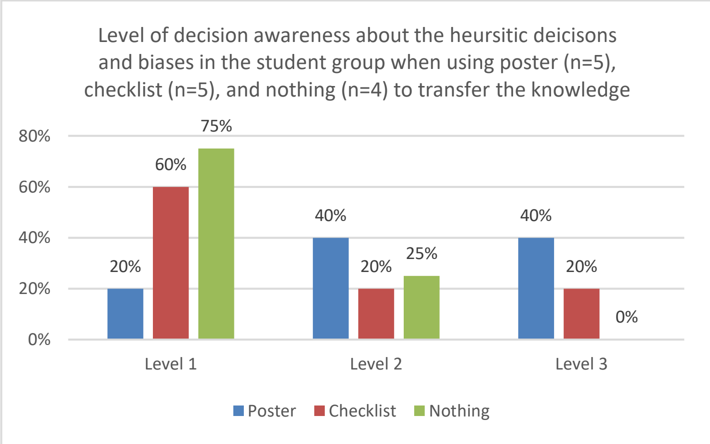


Figure 7.30: Level of decision awareness in the engineering group who used different materials to transfer knowledge

Participants in the poster group from students (72%) and engineers (40%) tend to be aware of heuristic decisions and biases. 40% of participants in the engineering group, tried to make a decision carefully and find some methods to avoid decision biases. On the other hand, most participants ($\geq 50\%$) in the checklist group of students and engineers, cannot recognize heuristic decisions and biases. When faced with heuristic decisions, the engineering in the poster group recognized it, and tried to apply de-biasing techniques. These results imply that knowledge from the poster encouraged the decision makers to recognize the heuristic decisions and biases and to apply de-biasing techniques to make decisions better than those based on other methods.

Results from the group who got no material also support the assumption that the video can only transfer information in a short period. It is necessary to find another material to remind information or knowledge about heuristic decisions and biases that will be then possible to reduce the decision biases based on awareness about it. Only training the participants before starting work or at the beginning of the project is not enough to increase their ability to make a decision and avoid decision bias. Reminding them during the working period by transferring information without requiring more effort is the better way to reduce heuristic decisions and biases.

The last evaluation is about motivation to know more about heuristic decisions regarding different materials to transfer information in the student group and the engineering group. The results are shown in Figure 7.31.

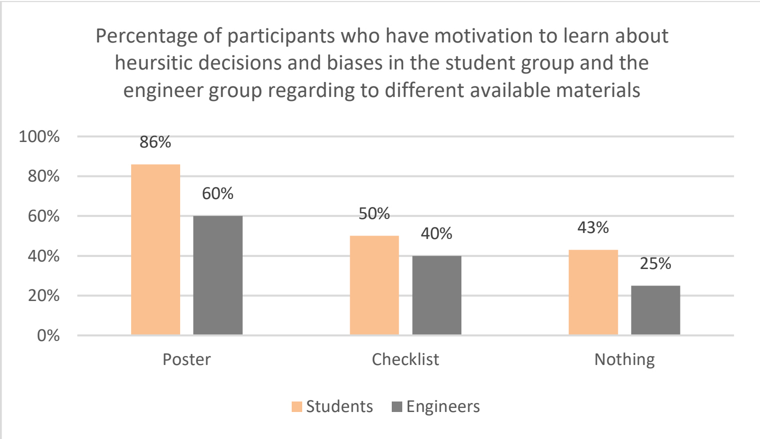


Figure 7.31: Results of participants who have the motivation to learn about heuristic decisions and biases in the student group and the engineering group regarding different materials.

Results from Figure 7.31 showed that using the poster to transfer knowledge has high efficient to motivate participants to learn about heuristic decisions and biases, especially in the student group. The motivation is decreasing when participants have to take much effort on it such as checklist material. Moreover, if no material is available to remind their previous knowledge, their motivations are also decreasing.

7.1.4 Conclusion

Results from this experiment show that the de-biasing technique by transfering the knowledge of heuristic decisions and de-biasing techniques can support the efficiency of decision making by avoiding and being aware of decision biases. The technique to transfer information is different, which also provides a different level of success. The video is a suitable material to motivate the decision maker to become aware of heuristic decisions and biases and learn more about them. This material can be used at the beginning of the project in a seminar. However, the knowledge from this material is not permanent. Therefore, material to remind information during working time is necessary. This material should be easy to understand and does not require extra effort from the decision maker. Based on this experiment, the poster that provides only information is the best to transfer and remind the decision maker's knowledge during the developing products in the working station. The level of success to de-biasing heuristic decisions depends on the level of awareness about heuristic decisions and biases and the level of ability to retrieve knowledge from the memory.

Nevertheless, these results come from the open questions that were answered directly from the decision makers. The results from these questions sometimes cannot represent the real behaviour in the situations. Therefore, observation or implicit questions should be applied to evaluate a successful of de-biasing technique in the future work. This evaluation can only show a successful of transferring knowledge to a decision maker. A successful of applying them in the real situation after having knowledge should also be evaluated in the future work.

7.2 Developing and evaluating the decision tool to transfer knowledge and provide feedback about heuristic decisions and biases to decision makers

In product development, there are many methods and strategies to support decision making as described in Section 2.2.4 and Section 2.5.5. However, available tools that are used to support decision making based on heuristic decisions are rarely available. The researcher, therefore, aims to develop the decision tool to support decision making based on heuristic decisions when prioritizing alternatives and selecting the final solution.

More so, this tool aims to reduce the appearance of decision biases caused by heuristic decisions during creating, evaluating, and selecting alternatives as shown in the experiments in Section 5, by implementing de-biasing techniques in type I and type II from the de-biasing framework in this tool. Figure 7.32 showed de-biasing techniques by increasing the decision maker's knowledge about the heuristic decisions and biases by showing the previous decision for the feedback.

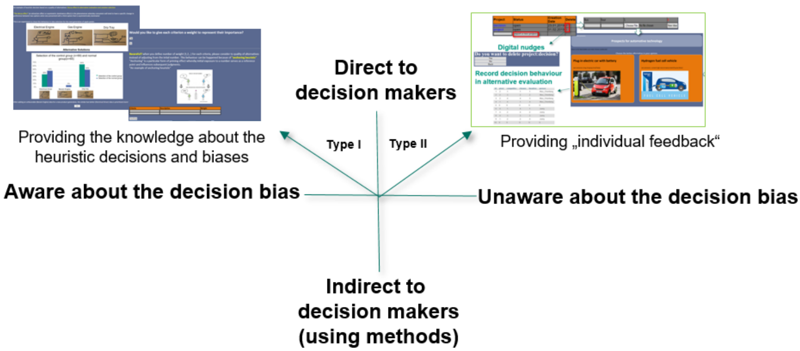


Figure 7.32: De-biasing technique type I and type II

This feedback was implemented in the tool to avoid or reduce the heuristic decisions and biases in specific situations such as creating components to evaluate alternatives and comparing alternatives. The technique in this tool is therefore different from the technique in Section 7.1 that leads the decision maker towards knowledge of the heuristic decisions and biases in general situations. After developing this tool with multiple functions to support decision making and reduce decision biases in alternative prioritization and solution selection, each function in the tool was then evaluated in activities of product development.

7.2.1 Developing the decision tool to support decision making in alternative prioritization and solution selection

This tool (Tanaiutchawoot, N., Bursac, N., Gross, J., Rapp, S., & Albers, A., 2020) is developed based on these fundamental requirements

1) Online process accessible from different platforms
2) Database storage of evaluation data and results
3) Evaluation support in multiple projects. This tool should be possible to create different projects in the same database.

According to these requirements, the tool is developed as a local database in a Web server using PHP and HTML language, which is run by the XAMPP program. This tool helps the decision maker to prioritize alternatives and select the solution using the pairwise comparison technique, which is a well-known algorithm to evaluate alternatives by comparing alternatives in each pair. If the total number of alternatives is equal to n, the number of times to compare alternatives is $\sum_{i=0}^{i=n}(i-1)$. This process takes much time to finish all comparisons. Therefore, the Quicksort algorithm is applied in this tool to prioritize and present alternatives in each pair (Gross, 2018), which is faster than the general pairwise comparison technique.

The Quicksort algorithm is one type of the sorting algorithm, which aims to rearrange an array of alternatives according to the amount of selection. Advantages of Quicksort algorithm that is better than other algorithms such as Bubble Sort and Merge Sort are providing a fast solution and require small additional amounts of memory to perform sorting factors. This algorithm relies on the principle of "divide-and-conquer", which works by setting a pivot element that divides the list of elements into 2 parts: before or after the pivot. After all alternatives or all competitor alternatives are compared with the pivot alternatives and ranked before and after the pivot, the sub-lists are then defined pivot elements of each group and recursively sorted by this pivot element of each group. These processes are repeated until all alternatives are ranked. The pivot alternative can be freely selected depending on the strategy and performance of the algorithm.

The pivot in this tool (Gross, 2018)[2] is selected from the middle alternatives when the number of alternatives is odd and selected from the left side of the middle alternatives when the number of alternatives is even. This algorithm supports the decision behavior of selecting the better alternative or selecting both alternatives. If the pivot alternative is selected to be better than the competitor alternative, the competitor alternative is assigned to the left side of the pivot. If the competitor is selected to be better than the competitor alternative, the competitor alternative is assigned to the right side. However, the competitor alternative will be attached to the pivot and has the same value as the pivot if both alternatives are equal and selected. Based on this algorithm to present alternatives and rank solutions, amount of times and effort to compare alternatives in pairs decrease.

Figure 7.33 shows an example of each case and algorithm to select, present and order alternatives using pairwise comparison and Quicksort algorithm in this tool.

[2] Master thesis

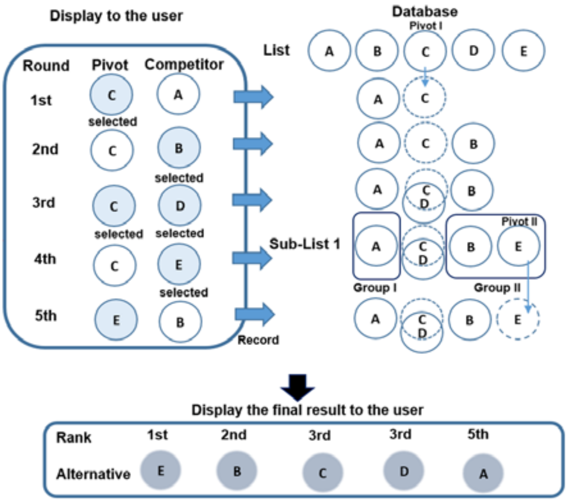


Figure 7.33: Comparing alternatives using the pairwise comparison algorithm and Quicksort algorithm

After all alternatives are ranked, the result shows a ranking from the best alternative (1st rank) to the worst alternative (n rank). The same rank will be assigned to the alternatives that are both selected in the comparison process. Comparing and prioritizing alternatives using this algorithm can reduce the number of comparisons and leads the proceeding time to be shorter, which is suitable for intuitive decision. Functions in the decision tool (Chenliang Mao, 2019; Zhao, 2019)[3] can be separated into 3 groups:

1) Main functions that aim to support decision making in alternative prioritization and solution selection such as creating the project, creating alternatives, creating criteria and weight, comparing alternatives using a pairwise-comparison algorithm, and exporting results (Liu, 2019; Tanaitchawoot, Mao, Liu & Rapp, Simon:Albers, Albert.).

2) Functions to provide knowledge about heuristic decisions and biases in each step in the tool such as providing information about the decoy effect when selecting alternatives with different quality level, explaining the influence of status-quo bias

[3] Co-supervisor of Master thesis

when evaluating alternatives, describing the appearance of anchoring and adjustment heuristic when working, identifying the weight for each criterion, and explaining an influence of social bias when reviewing a group result before starting evaluation. These functions are the de-biasing technique type I, which will be successful to reduce decision bias if the decision maker is aware of the decision bias and tries to ensure that the decision is not influenced by that bias during making a decision.

3) Functions provide feedback based on personal previous decisions in order to avoid decision errors such as a warning message when deleting alternatives, criteria, or results. Another warning indicator is the repetition of decision behavior from the previous selection in the comparison process such as selecting the same alternatives 3 times or rejecting the same alternative 3 times. Functions in this group are the de-biasing technique type II that does not require an awareness of heuristic decisions and decision biases. The decision maker will get feedback on his/her decision reminiscent of his/her decision, which can reduce decision bias if the decision maker rethinks his/her decision and changes from fast thinking to slow thinking.

Relationships of each function are shown in Figure 7.34; each function in each page of the decision tool will be explained in the further step.

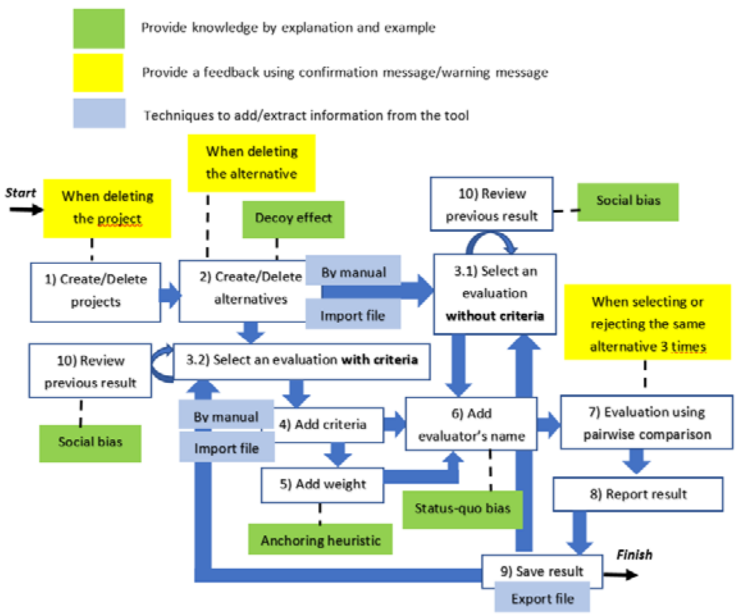


Figure 7.34: Functions and connections of each function in the decision tool

Create or delete projects

The first page of this tool is to show an overall project including the project's name, types of projects (Open/New), and date created. The button initializes a project that is used to generate a new project after filling the project's name in the blank space. Figure 7.35 shows components on the first page.

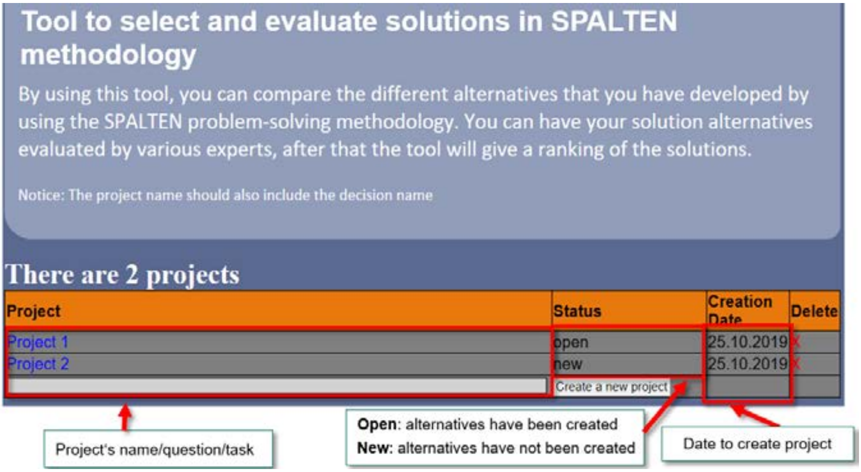


Figure 7.35: The first page of the decision tool for creating/deleting projects

Before the project is deleted, a confirmation message will ask to confirm the decision as shown in Figure 7.36. This function is added to avoid decision errors by the decision maker. This is one technique in the nudging process that supports decision making. The decision maker has a chance to rethink the decision and provide confirmation. This technique is applied for deleting alternatives, criteria, and results.

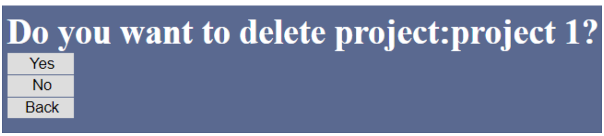


Figure 7.36: Confirmation message when deleting the project

Create or delete alternatives

After creating the project, alternatives are then generated using 2 methods: manual or by import from an excel file as shown in Figure 7.37.

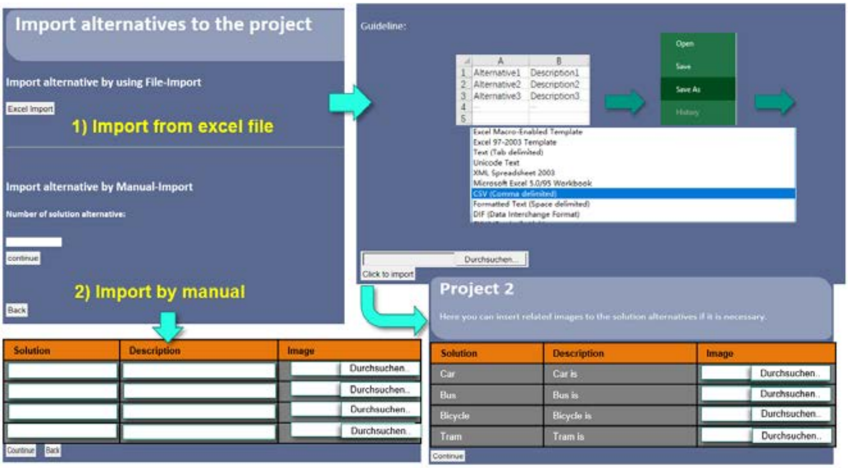


Figure 7.37: The second page of the decision tool for creating/deleting alternatives

Import from excel file is suitable when there are many alternatives and information. This function supports a decision maker to link information from other platforms to the decision tool without exerting a lot of effort. However, this function is suitable for the CSV file with the strict template. The first column is the name of the alternative; the second column is the description. The decision maker can decide to add a description or not. After that, the decision maker can decide to upload pictures for each alternative or not. These components are shown in Figure 7.37.

The second method to create an alternative is manually. The decision maker fills in the number of alternatives in the beginning and then 3 columns with the name of alternative, description, and uploaded image files.

During the process of creating alternatives, a warning about decoy effect is shown that aims to provide knowledge and example of the heuristic decision when the quality of alternatives are different. Figure 7.38 shows the warning of the decoy effect and a button to link to another page that provides an explanation and example of the decoy effect. This example warns the decision maker about decision bias when the quality of alternatives is not similar. The alternative with similar but better quality than the other alternative seems interesting and is selected more often than the

alternative that has a different idea but also higher in quality when compared to the other alternatives.
To avoid this bias, the decision maker should create alternatives that have similar quality and different ideas/concepts. If some alternatives have similar ideas/concepts, the decision makers should group them or be aware of them when comparing alternatives. Providing knowledge about heuristic decision and bias in a specific situation is also a technique to avoid heuristic decision and bias, and support decision making. The decision maker can apply the knowledge in the real situation, which is a higher potential than providing knowledge in general situations.

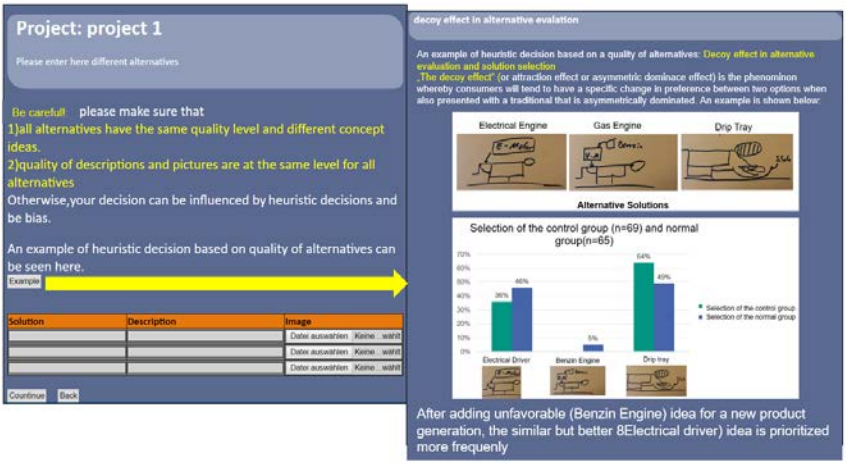


Figure 7.38: Providing knowledge of the decoy effect

Select an evaluation with/without criterion

When alternatives are created by the previous method, an overview of all alternatives is shown in the table. The decision maker can edit or add more alternatives. Then a technique to compare alternatives is selected with or without criteria. The button "Yes, start to insert criterion" is clicked when the decision maker prefers to make a decision with criteria. If the decision maker decides to make an evaluation without criteria, the decision maker can start evaluation by inserting the decision maker's name then clicking "start a new evaluation" (without criterion). All details are shown in Figure 7.39.

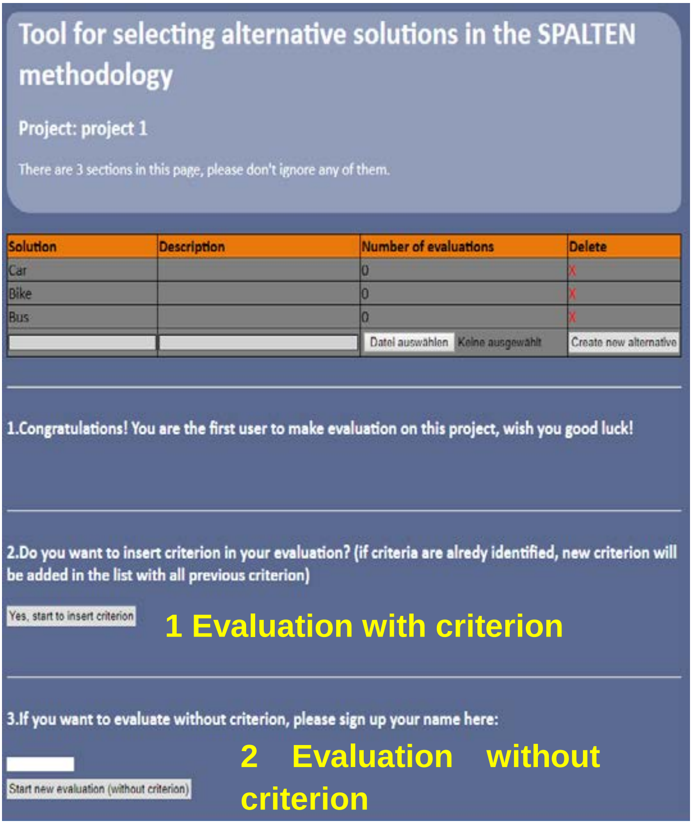


Figure 7.39: Select a type of evaluation (with/without criterion)

Add criteria

Criteria can be created by adding criteria manually and importing from the excel file, which is shown in in Figure 7.40 (Liu, 2019). The technique to create criteria is similar to the technique to create alternatives in Section 7.2.1.2. Template and type of excel file are also the same.

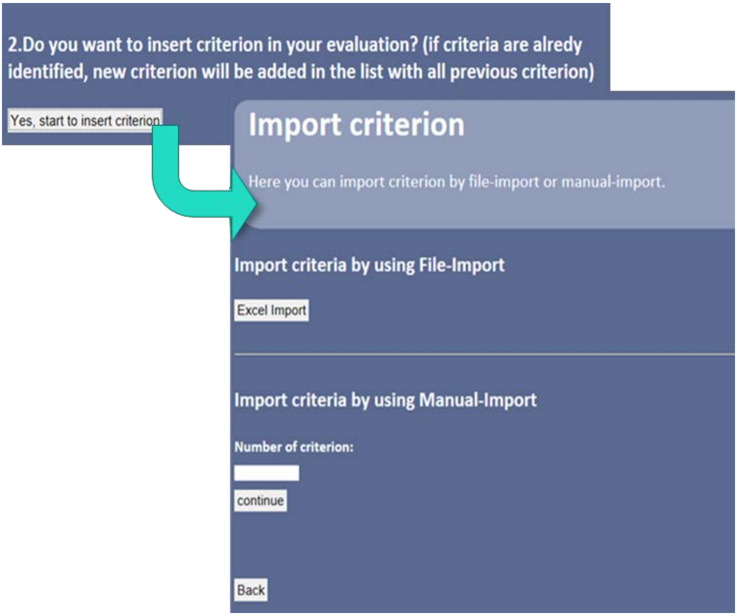


Figure 7.40: Create criteria by importing from excel file and by manual

Add weight

Weighted criteria is another component that is required to define the value of each criterion. This component helps the prioritization process to be more efficient. Each criterion sometimes has a different level of importance, defining weight can help a calculation to be more precise. However, weighted criteria can be ignored if all criteria are no different from the level of importance or lack of information. Figure 7.41 shows the page to add weight in criteria or not.

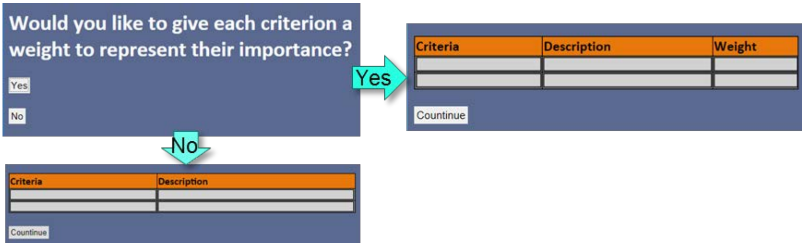


Figure 7.41: Adding weight or not to each criterion

During this process, one important heuristic can be influenced in decision making, which is an anchoring bias. When defining the weight for each criterion, the decision maker can decide and adjust the number based on the initial number. Therefore, this program provides knowledge using explanation and example as shown in Figure 7.42 to warn the decision maker before defining the number of the weight.

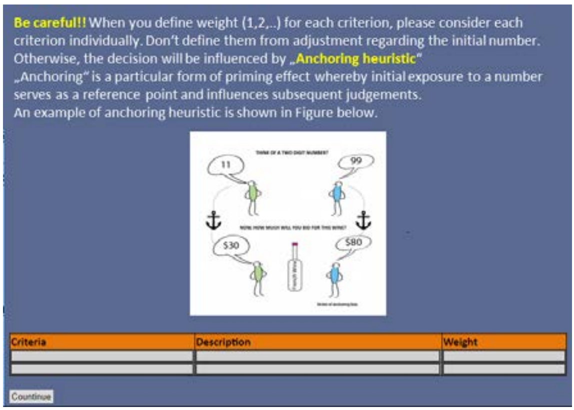


Figure 7.42: Providing knowledge about anchoring bias

Add evaluator's name

Before starting an evaluation, the decision maker has to register his/her name as shown in Figure 7.43. This function is appropriate for an evaluation in a group. However, the decision maker can see only a group evaluation and his/her history of evaluations. The decision can register with an anonymous name to avoid taking responsibility for his/her decision.

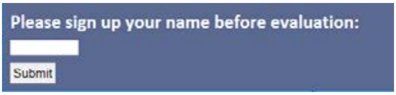
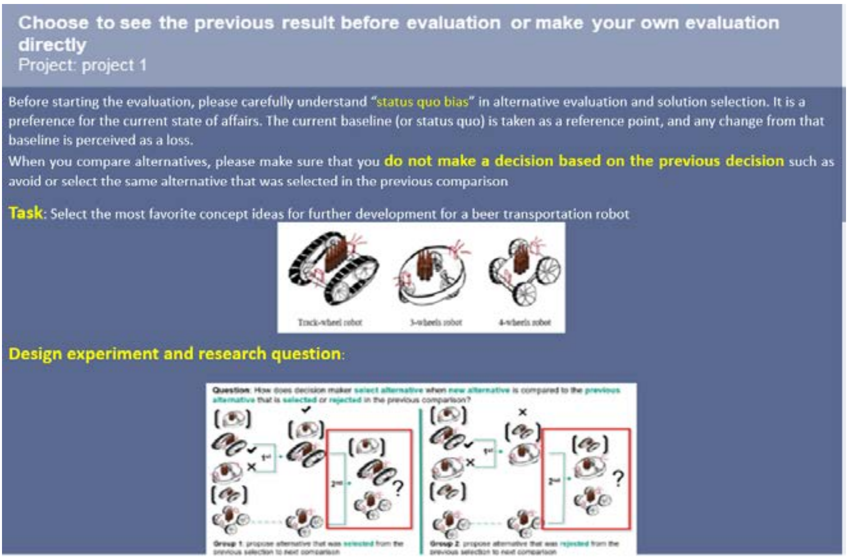


Figure 7.43: A registration page to identify the decision maker

Another piece of knowledge of the heuristic decision that is provided in the step is a status-quo bias. This knowledge aims to warn the decision maker before starting an evaluation in a pairwise comparison. The decision maker usually makes the decision based on the previous decision and tries to keep the same decision such as rejecting or selecting the same choice to avoid regretting his/her new decision. Explanation and example are provided as shown in Figure 7.44.



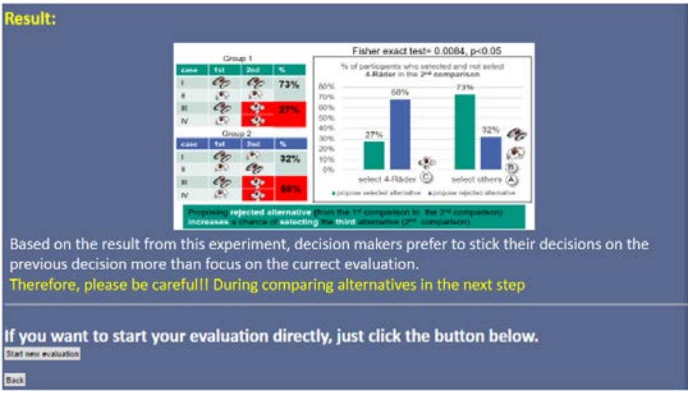


Figure 7.44: Providing the knowledge about a status-quo bias

Evaluation using pairwise comparison

This page is the main page to compare alternatives in pairs. The decision maker selects the alternative that is better than the other alternative or selects the "Equal" button when both alternatives are equal. Figure 7.45 shows components on the evaluation page.

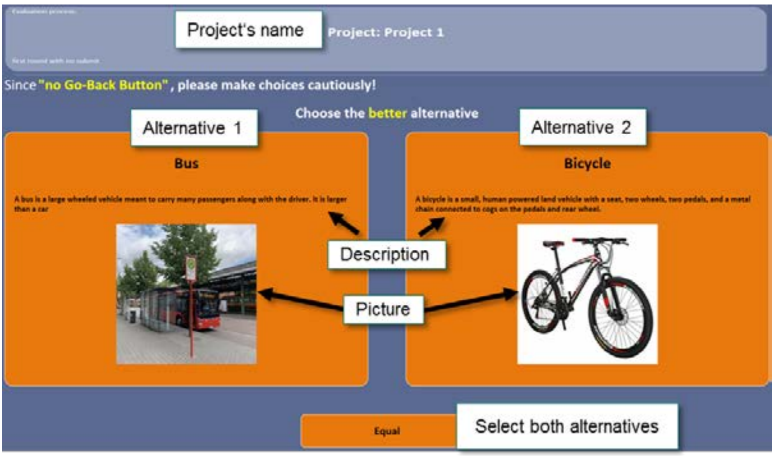
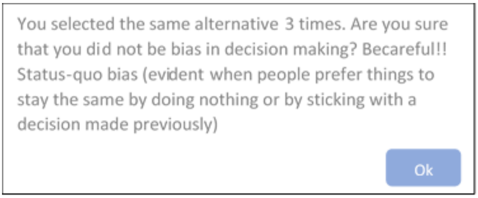


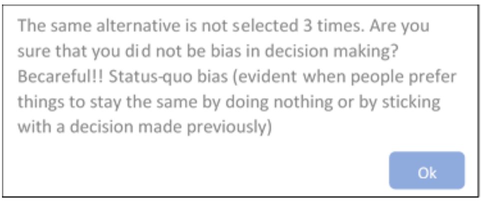
Figure 7.45: The evaluation with pairwise comparison

The algorithm to present and prioritize alternatives is the Quicksort algorithm. Details of this algorithm were explained in the section algorithm of the decision tool. Many tools usually provide only the alternative name; however, this tool implements description and picture to help the decision maker to have a better understanding of each choice. However, the quality of the description and pictures can also influence decision making.

During the comparison process, a warning message about the decision behavior will pop up to provide feedback that the same alternative is selected or rejected 3 times (in Figure 7.46). The decision behavior is tracked to give feedback when the decision maker seems to have a decision bias based on status-quo bias.



A



B

Figure 7.46: A warning message when A) the same alternative is selected 3 times, and B) the same alternative is rejected 3 times

Report result

Figure 7.47 shows 4 tables of results that are

1) A combined result without criteria
2) A combined result with criteria
3) The result from the current evaluation
4) A history result from the individual evaluation.

Notice!!: Before you leave this page, please **"save"** the result

1) All results without criteria

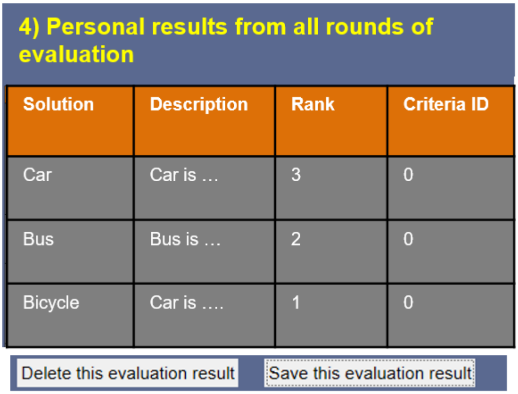
Solution	Description	Rank
Bicycle	Bicycle is …	1
Bus	Bus is …	2
Car	Car is ….	3

2) All results with all criteria

Solution	Description	Rank
Car	Car is …	0
Bus	Bus is …	0
Bicycle	Car is ….	0

3) Results from current evaluation

Solution	Description	Rank
Bicycle	Bicycle is …	1
Bus	Bus is …	2
Car	Car is ….	3


4) Personal results from all rounds of evaluation

Solution	Description	Rank	Criteria ID
Car	Car is …	3	0
Bus	Bus is …	2	0
Bicycle	Car is ….	1	0

Delete this evaluation result | Save this evaluation result

Figure 7.47: Report results

The results are described with the ranking number. The best solution is defined by the lowest number of each rankings (1), and the worst solution is defined by the highest number of each rankings. If the number of ranking is 0, that means there is no evaluation. The result in the first table is the combined result from different decision makers and iterations without criteria. If there is no evaluation of this type (without criteria), the ranking will show 0. The result in the second table is a combined result from different decision makers and iterations with all criteria. If there is no evaluation in this type (with criteria), the ranking will also show 0. The result in the third table is only the result of the current evaluation. The result in this table can be the result with a specific criterion or without criterion. The result from this table will be saved in the fourth table when making another round of evaluations. The result in the fourth table contains all personal results. This table recorded all evaluations including the result without criteria, the result with different criteria, and the results from all iterations. This table helps the decision maker to review his/her decision from different environments and time.
The decision maker can decide to delete or save the result in the system. When the decision maker leaves this page without saving the result, the current result will be deleted. Therefore, it is necessary to save the result before leaving the page.

Save result

The results can be saved and exported to an excel file to be used in the further step. The decision maker can select export different results based on his/her objective as shown in Figure 7.48.

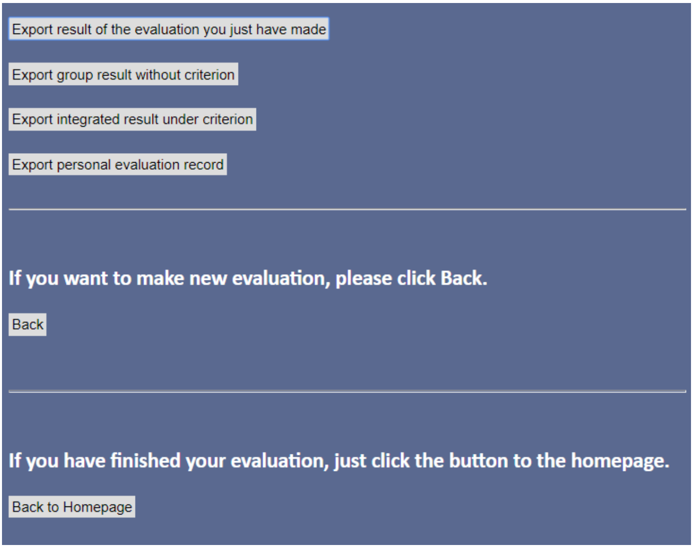


Figure 7.48: Save and export results

“Export results of the evaluation you just have made” is suitable for comparing your result with other decision makers in a discussion. The result of this file is not influenced by the group’s decision. If the decision makers would like to find the final groups’ decision, “Exporting group result without criteria” and “Exporting integrated result under criteria” can be used. The decision maker can compare the results from 2 types of decision making and select the final result. Results from different types of decision making can also be used to evaluate an efficient method of decision making. In some situations, making a decision without criteria can provide a good result because the decision maker does not have to make a decision within a specific scope.
The last result is a history of the personal evaluation. This file can provide a value when the decision maker wants to find a consistency of his/her decision and decisions in different situations. If the evaluation is still not completed, the decision maker can skip export the result and click “Back” to make another evaluation. The decision maker can also go back to the homepage to make an evaluation in other projects or edit some information such as alternatives or criteria in the same project.

Review the previous result

This function will appear before starting to evaluate alternatives if the evaluation has been done. Even though this function can help the decision maker to have basic information on evaluation from different persons, this function can lead the decision to be bias based on social bias. The decision maker will try to make a decision based on a groups' decision and is no confidence in his/her decision. Therefore, this tool provides a caution about the social bias with a description before reviewing the previous result. The decision maker has a chance to change his/her decision to review the previous result by not clicking "continue" or by selecting "back". Figure 7.49 shows an example of reviewing the previous result on the page for evaluating alternatives with criteria and the knowledge about social bias.

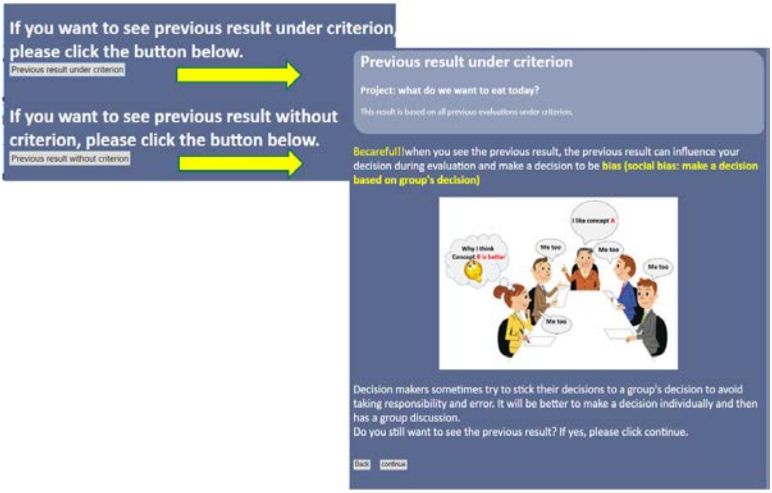


Figure 7.49: Review the previous result and the knowledge about social bias

Functions in the database

Functions, as described previously, are shown to support decision making in each process, to evaluate alternatives, and select the solution. However, there is another group of functions that is used to investigate decision behavior without the decision maker's awareness. These functions include

1) The function to record all steps when using this tool starting from creating a project until export the result in Figure 7.50

2) The function to record selection behavior when comparing alternatives in the pairwise-comparison and Quicksort algorithms in Figure 7.51.

These functions help the researcher to investigate and understand the decision behavior without interrupting the decision maker during an experiment. Moreover, this information helps the decision maker to evaluate the potential of functions aimed to reduce the decision biases.

id	action	registration	time
1	New project created		2019-09-12 20:23:06
2	Manual-import alternative		2019-09-12 20:23:26
3	Manual-import alternative		2019-09-12 20:24:01
4	Add new alternative		2019-09-12 20:24:14
5	Add new alternative		2019-09-12 20:24:21
6	Add new alternative		2019-09-12 20:24:28
7	Add new alternative		2019-09-12 20:24:35
8	Add new alternative		2019-09-12 20:24:41
9	evaluating without cri now	fah	2019-09-12 20:24:52
10	evaluating without cri now	fah	2019-09-12 20:40:48
11	evaluating without cri now	fah	2019-09-12 20:49:28
12	evaluating without cri now	fah	2019-09-12 20:54:37
13	evaluating without cri now	fah	2019-09-12 20:56:27
14	evaluating without cri now	fah	2019-09-12 21:14:28
15	Delete the evaluation result after eva without cri		2019-09-12 21:14:56
16	evaluating without cri now	fah	2019-09-12 21:15:07
17	evaluating without cri now	fah	2019-09-12 21:18:00
18	evaluating without cri now	fah	2019-09-12 21:24:18

Figure 7.50: The results of function in the database to record actions or steps when using the decision tool

	id	pivot	competitor	chosen	iteration	person
Löschen	1	.3.	.1.	.3.	.1.	.fah.
Löschen	2	.3.	.2.	.3.	.2.	.fah.
Löschen	3	.3.	.4.	.3.	.3.	.fah.
Löschen	4	!	!	!	!	!
Löschen	5	.3.	.5.	.5.	.4.	.fah.
Löschen	6	.3.	.6.	.6.	.5.	.fah.
Löschen	7	.5.	.6.	.5.	.6.	.fah.
Löschen	8	.2.	.1.	.1.	.7.	.fah.
Löschen	9	.2.	.4.	.4.	.8.	.fah.
Löschen	10	.1.	.4.	.1.	.9.	.fah.
Löschen	11	9	9	9	9	9

Figure 7.51: The results of function in the database to record alternatives and selection in each pair in the pairwise-comparison process

Figure 7.50 shows the example of actions that were recorded when using the tool. Not only the actions in the tool, the person who works on this tool, date, and time are also recorded. Figure 7.51 shows an example of recording information. Alternatives are represented by the id that is recorded in the table. Pivot alternative, comparator alternative and the selected alternative in each round were recorded to investigate the decision behavior in an alternative selection based on the techniques and sequences to present alternatives. The person who makes a decision is also recorded to distinguish a person's decision behavior. When all alternatives are finished comparing, number "9" as shown in id 11 is added to separate decision making in each round. The symbol "!" in id 4 shows the appearance of a warning message when the same alternatives are continuously selected 3 times. If the decision maker continuously rejected the same alternative 3 times, the symbol "!!" will be added to the table. Based on this recording, the decision behavior and the performance of the de-biasing technique can be investigated.

7.2.2 Experiment to evaluate de-biasing technique type I in the decision tool in Experiment 1

This decision tool was applied in 2 workshops, which aimed to prioritize alternatives using pairwise-comparison.

The first experiment was done in the workshop that aims to identify the field of action with the most potential for the company in terms of a change toward agility. Nine actions are defined for alternatives and required a ranking using this tool. Each action is presented by the id number from 1 to 9. There were 2 participants who evaluated alternatives in the same project in this experiment. The first participant is the master student in the department of mechanical engineering at KIT University. The second participant is the engineer who was a project header in the one company. The decision tool is developed to support this specific evaluation and is sent to the decision makers via online web-link with the manual for using the decision tool. The tool was introduced to one of the participants to provide basic information before using the tool such as steps to create alternatives (import from excel file, manual), options for evaluating alternatives (with-without criteria, with-without weight) and the meaning of results in each table, which takes around 10 minutes. After the decision maker understands the basic functions in the decision tool, the first participant starts creating alternatives and evaluating alternatives. Then the second participant makes another evaluation based on the same alternatives that were created by the first participant. However, both of them made an evaluation under different environments. The first participant made an evaluation under one criterion, and the other participant made an evaluation without criterion. These actions were recorded in the database to investigate actions when using the decision tool as shown in Table 7.1.

Table 7.1: Actions in the decision tool to evaluate 9 alternatives in Experiment 1

id	Action	Decision makers
1	new project created	
2	manual-import alternative	
3	manual-import alternative	
4	insert criteria	
5	Manual-import criteria	
6	Manual-import Criteria	
7	Choose not to give weigh to the criteria	
8	Evaluating under cri now	Participant 1
9	Save the evaluation result after eva with cri	
10	evaluating without cri now	Participant 2
11	Click check result under criteria in without criteria	
12	.. (back: cancel review..)	
13	evaluating without criteria now	
14	Save evaluation result after eva without criteria	

The result of action in id 12 presents that the decision maker changed his mind to check the result after getting a warning message in the tool. Selection behavior in pairwise comparison from the first and the second participants are also recorded and presented in Table 7.2. Id 8 in the table shows an appearance of the warning message, which will be analyzed in the evaluation section.

Table 7.2: Results of decision making in the pairwise-comparison algorithm from participant 1 and participant 2 in Experiment 1

id	pivot	competitor	chosen	iteration	person
1	5	1	5	1	Participant1
2	5	2	Both	2	Participant1
3	5	3	5	3	Participant1
4	5	4	4	4	Participant1
5	5	6	6	5	Participant1
6	5	7	Both	6	Participant1
7	5	8	8	7	Participant1
8	!!	!!	!!	!!	!!
9	5	9	5	8	Participant1
10	6	4	Both	9	Participant1
11	6	8	8	10	Participant1
12	3	1	3	11	Participant1
13	3	9	Both	12	Participant1
14	9	9	9	9	9
15	5	1	5	1	Participant2
16	5	2	2	2	Participant2
17	5	3	5	3	Participant2
18	5	4	5	4	Participant2
19	5	6	Both	5	Participant2
20	5	7	5	6	Participant2
21	5	8	8	7	Participant2
22	5	9	9	8	Participant2
23	8	2	8	9	Participant2
24	8	9	8	10	Participant2
25	3	1	1	11	Participant2
26	3	4	3	12	Participant2
27	3	7	3	13	Participant2
28	2	9	2	14	Participant2
29	4	7	7	15	Participant2
30	9	9	9	16	Participant2

Another method to evaluate the de-biasing techniques type I and type II in the decision tool is a questionnaire. The questionnaire was answered only from the first participant. Another participant did not create the project and alternatives; therefore, this questionnaire was skipped for the second participant. There are 4 objectives that are used to evaluate the efficiency of de-biasing techniques in the tool, which are evaluating the knowledge, an awareness after getting the knowledge, advantages of components in the tool, and the reliability of decision making when using this tool. The result based on this questionnaire from the first participant is shown in Table 7.3.

Table 7.3: The result from one participant in Experiment 1 based on the questions in the questionnaire

Questions	Objective	Answer options
Do you have **more knowledge** about heuristic decisions and biases when using this decision tool?	Check knowledge	❑ Yes: I know more about types of heuristic decision ❑ Yes: I know more about the influence of each heuristic decision to the alternative prioritization process ☑ Yes: I have more knowledge and try to apply the knowledge during making the decision to reduce decision biases regarding examples ❑ Yes:... ❑ No
Did you try to **avoid decision errors** based on heuristic decisions and biases that are described in the decision tool?	Aware of decision biases after getting the knowledge	Yes: I try to be patient and to avoid an influence of heuristics and biases when making a decision regarding examples when ☑ Creating alternatives ❑ Defining weight for each criterion ☑ Compare alternatives ❑ No: I did not think about it

Questions	Objective	Answer options
Which **functions to avoid heuristic** decisions did you **encounter**?		☑ An example of the decoy effect when creating alternatives ☑ An example of status-quo bias before starting comparison of alternatives ☐ An example of anchoring heuristic when defining weight for each criterion ☑ A warning message when you have the same style of selection (select the same/different alternatives) ☑ A warning message when you want to delete project/alternatives/criteria ☐ A warning text about reviewing the previous result (group's result, results with/without criteria) ☐ No function ☐ Others…..
Which **functions to avoid heuristics and biases** are an **advantage** for you?	Advantage of components in the tool	☑ An example of the decoy effect when creating alternatives ☑ An example of status-quo bias before starting comparison of alternatives ☐ An example of anchoring heuristic when defining weight for each criterion ☑ A warning message when you have the same style of selection (select the same/different alternatives) ☐ A warning message when you want to delete project/alternatives/criteria ☐ A warning text about reviewing the previous result (group's result, results with/without criteria) ☐ No function ☐ Others…..
How do those functions **advantage** for you?		☐ I can change my decision after getting a warning message (delete…, save results, review the previous result) ☑ I can notice my previous decision and focus more on the current decision ☐ I think carefully when I get feedback from my decision (warning messages) and get the knowledge about heuristic decisions and biases (examples) ☐ others…….

Questions	Objective	Answer options
Do you **use the result** from this tool in **the further step?**	Check reliability of decision making when using this tool	❑ Yes: 100% ❑ Yes: 75% ☑ Yes: 50% ❑ Yes: 25% ❑ No

Results from Table 7.1-Table 7.3 are then analyzed based on the types of de-biasing techniques in the decision tool.

1.1.1.1 Evaluating de-biasing techniques type I in the decision tool in Experiment 1

There are 2 techniques to evaluate the results of functions in the decision tool, which are database in the tool and questionnaire. The database is used to investigate the responding from the user to functions in the tool. The questionnaire is used to evaluate the efficiency of functions in the decision tool to transfer knowledge and awareness about the heuristic decisions and biases in each situation.

Results from Table 7.3 show an estimation from the decision maker that he has more knowledge about the heuristic decisions and biases that can appear in each step of alternative evaluation. Moreover, the decision maker tries to apply the knowledge to avoid the bias based on the suggestion from the function to provide the knowledge such as creating the alternatives with the same quality level to avoid the decoy effect. Moreover, the decision maker tries to carefully make a decision when comparing alternatives. The participant seems to be satisfied with all functions that provide information about the heuristic decisions and biases and try to apply the knowledge to improve decision making. One example can be seen in Table 7.1. At the beginning of the evaluation, the second participant aimed to review the result of the evaluation from the first participant. After getting the knowledge about social bias if reviewing the previous result, the second participant changed his mind and started making an evaluation without reviewing the result. The function that provided information about the anchoring and adjustment heuristic is not evaluated in this experiment because the evaluations were made only with and without criteria. Weighting for each criterion was not defined. Even though, a number of results from this experiment are small to make a conclusion, these results from the questionnaire and the database provide a positive feedback regarding to de-biasing techniques in the decision tool to reduce the biases by increasing the awareness about the heuristics and biases in decision making during creating and evaluating alternatives.

1.1.1.2 Evaluating de-biasing techniques type II in the decision tool in Experiment 1

Providing the personal feedback to remind the decision maker about his/her previous decision is the de-biasing technique type II that was applied in this tool when deleting the project, alternatives, and criteria. This function was also applied in the comparison process when selecting solution in each pair of comparison. The efficiency of the de-biasing technique when providing feedback during selecting alternatives in the comparison process can be seen in

Table 7.2. The first participant got the warning message (id 8) about continuously rejecting the same alternative 3 times. After that, the participant changed his style of selection behavior. This result is confirmed by the result in the questionnaire that the participant could notice his/her previous decision and focused more on the current decision. Results from both methods show the efficiency of de-biasing techniques by providing the individual feedback about his/her previous decision can reduce a chance to make the decision biases and errors such as keep rejecting the same alternative without anawareness. However, there are other functions that are not tested in this experiment such as the feedback after deleting alternatives or criteria.

This decision tool was implemented in the second workshop that aimed to select influence factors in the scenario activity for future management in one company. 20 influence factors were created, but only 10 influence factors were required for the further step. This tool is, therefore, used to prioritize these 20 influence factors and find the top 10 influence factors. These influence factors were represented by the alternative id from 1 to 20. The participants in this workshop were 3 mechanical engineering students who were in charge of developing a scenario for future management. The decision tool was introduced to one of the participants to inform them of the functions and processes in order to make an evaluation with this tool. This participant also took responsibility to prepare this evaluation. Then the other participants made evaluations individually using this tool. Table 7.4 showed the result from the database that records all actions in this tool regarding this project from 3 participants.

Table 7.4: Actions in the decision tool from 3 participants to prioritize 20 influence factors in Experiment 2

Id	Action	Decision makers
1	new project created	
2	File-import alternative	
3	File-import alternative	

Id	Action	Decision makers
4	File-import alternative	
5	evaluating without cri now	Participant 1
6	Save the evaluation result after eva without cri	
7	evaluating without criteria now	Participant 2
8	Click check result without cri in without criteria	
9	.. (back: cancel review..)	
10	evaluating without criteria now	
11	Save the evaluation result after eva without cri	
12	evaluating without criteria now	Participant 3
13	Save the evaluation result after eva without cri	
14	Export group result without cri after eva without ...	
15	Export group result without cri after eva without ...	

Selection behavior in pairwise comparison from 3 participants was recorded in the database. A number of comparisons in the first participant, the second participant, and the third participant are 51, 54, and 47 times, respectively. Based on a high number of comparisons, only the comparisons that evoke the warning message from 3 participants are shown in Table 7.5.

Table 7.5: Results of decision making in the pairwise-comparison algorithm from 3 participants in Experiment 2

id	pivot	competitor	chosen	iteration	person
5	10	5	5	5	participant1
6	10	6	6	6	participant1
7	10	7	7	7	participant1
8	!!	!!	!!	!!	!!
9	10	8	10	8	participant1
21	13	3	13	20	participant1
22	13	5	13	21	participant1
23	13	6	13	22	participant1
24	!	!	!	!	!
25	13	7	7	23	participant1
35	8	9	9	33	participant1
36	8	12	12	34	participant1

id	pivot	competitor	chosen	iteration	person
37	8	15	15	35	participant1
38	!!	!!	!!	!!	participant1
39	8	18	18	36	participant1
57	14	11	11	2	participant2
58	14	17	17	3	participant2
59	14	7	7	4	participant2
60	!!	!!	!!	!!	!!
61	14	13	14	5	participant2
86	8	13	13	30	participant2
87	8	6	6	31	participant2
88	8	3	3	32	participant2
89	!!	!!	!!	!!	!!
90	8	1	8	33	participant2
101	6	13	6	44	participant2
102	6	3	6	45	participant2
103	6	18	6	46	participant2
104	!	!	!	!	!
105	6	2	2	47	participant2
114	4	17	17	1	participant3
115	4	11	11	2	participant3
116	4	7	7	3	participant3
117	!!	!!	!!	!!	!!
118	4	19	4	4	participant3
122	4	15	15	8	participant3
123	4	16	both	9	participant3
124	4	6	6	10	participant3
125	!!	!!	!!	!!	!!
126	4	13	4	11	participant3
137	8	11	11	21	participant3
138	8	7	7	22	participant3
139	8	10	10	23	participant3
140	!!	!!	!!	!!	!!
141	8	5	both	24	participant3

The result of the questionnaire in Table 7.6 was done by the first participant who created and managed the evaluation in this project. Therefore, this participant has more chances to get knowledge about heuristic decisions and biases from examples in different functions of the decision tool.

Table 7.6: The result from one participant in experiment 2

Questions	Objective	Answer options
Do you have **more knowledge** about heuristic decisions and biases when using this decision tool?	Check knowledge	❑ Yes: I know more about types of heuristic decision ❑ Yes: I know more about the influence of each heuristic decision to the alternative prioritization process ☑ Yes: I have more knowledge and try to apply the knowledge during making the decision to reduce decision biases regarding examples ❑ Yes:... ❑ No
Did you try to **avoid decision errors** based on heuristic decisions and biases that are described in the decision tool?	Aware of decision biases after getting the knowledge	Yes: I try to be patient and to avoid an influence of heuristics and biases when making a decision regarding examples when ☑ Creating alternatives ❑ Defining weight for each criterion ☑ Compare alternatives ❑ No: I did not think about it
Which **functions to avoid heuristic** decisions did you **encounter**?		☑ An example of the decoy effect when creating alternatives ☑ An example of status-quo bias before starting comparing alternatives ❑ An example of anchoring heuristic when defining weight for each criterion ☑ A warning message when you have the same style of selection (select the same/different alternatives) ❑ A warning message when you want to delete project/alternatives/criteria

Questions	Objective	Answer options
		❑ A warning text about reviewing the previous result (group's result, results with/without criteria) ❑ No function ❑ Others…..
Which **functions to avoid heuristics and biases** are **advantages** for you?	Advantage of components in the tool	☑ An example of the decoy effect when creating alternatives ☑ An example of status-quo bias before starting comparison of alternatives ❑ An example of anchoring heuristic when defining weight for each criterion ☑ A warning message when you have the same style of selection (select the same/different alternatives) ❑ A warning message when you want to delete project/alternatives/criteria ❑ A warning text about reviewing the previous result (group's result, results with/without criteria) ❑ No function ❑ Others…..
How do those functions **advantage** for you?		❑ I can change my decision after getting a warning message (delete…, save results, review the previous result,…) ☑ I can notice my previous decision and focus more on the current decision ☑ I think carefully when I get feedback from my decision (warning messages) and get the knowledge about heuristic decisions and biases (examples) ❑ others…….

Questions	Objective	Answer options
Do you **use the result** from this tool in **the further step?**	Check reliability of decision making when using this tool	❑ Yes: 100% ☑ Yes: 75% ❑ Yes: 50% ❑ Yes: 25% ❑ No

Results from these 3 tables (Table Table 7.4-Table 7.6) are analyzed in the next part to evaluate the performance of de-biasing functions type I and type II in the decision tool.

1.1.1.3 Evaluating type I de-biasing techniques with the decision tool in Experiment 2

Results from the second workshop are quite similar to the results of the first workshop. The participant gets more knowledge about the heuristic decisions and biases that possibly appeared in the evaluation process. Moreover, the participant tried to apply the knowledge from examples in the real situation. This analysis is supported by the information in the database from the 2nd participant who changed his/her mind to review the previous evaluation after getting the information about social bias. This result was also similar to the result of the first workshop. Therefore, the results from the second workshop also support the results from the first workshop. De-biasing techniques type 1 by providing knowledge about the heuristic decisions and biases in the specific situation in the tool can reduce the chance of appearance of decision errors and biases when evaluating alternatives and selecting the solution.

1.1.1.4 Evaluating type II de-biasing techniques of the decision tool in Experiment 2

Providing feedback during comparing alternatives to help the decision makers rethink their previous decisions is only one function that can be evaluated in this workshop similar to workshop 1. After getting the feedback from the warning message, the participants try to adjust their decisions to avoid the same behavior. If the warning reminds the decision maker about selecting the same alternatives 3 times, the decision maker tried to avoid selecting the same alternative in the next comparison, which can be seen in id 24 and id 104 in Table 7.5. On the other hand, if the warning reminds the decision maker about rejecting the same alternative, the decision maker tended to select the alternative that he/she rejected previously in the next comparison. The examples of this case are shown in id 8, 60, 89, 117, and 125 in Table 7.5. These two behaviours are caused by the status-quo bias.

It is also possible that the decision maker did not change his/her mind regarding the feedback from the warning message. If the decision maker is aware of his/her decisions, he/she will retain his/her decision which can be seen in id 38 and 140 in Table 7.5. Different decision behavior from the database implies that the individual feedback function in the decision tool reminded the decision makers of their previous decisions and gave more time to rethink the current decision. The technique can reduce decision bias such as status-quo bias in decision making.

7.2.3 Conclusion

The decision tool is developed to support decision making when prioritizing alternatives and selecting the solution. The tool also helps the researcher to investigate decision behavior when evaluating alternatives without interrupting the decision maker. Moreover, de-biasing functions such as providing knowledge and individual feedback can also be implemented to reduce influences of heuristic decisions and biases during the processes of evaluation, which helps the results from this tool are more reliable. Applying the digitalization to detect decision behavior and support decision making is one interesting technique that should be further developed in the future. Results from this experiment show the efficiency of the de-biasing technique in type I and type II, which helps the decision maker to be aware of decision bias and influences of heuristic decisions in specific activities. Moreover, the decision maker has more chance to review his/her previous decision from the feedback, which reduces the decision error from unconscious decisions. On the other hand, feedback can also lead the decision to be biased by avoiding making the same decision as the previous decision- even if that decision is correct. This example can be seen from many participants who changed the selection behavior after getting the warning message about the previous selection (continuously selecting or rejecting the same alternatives 3 times).

Results from this tool are only the beginning step of evaluation. More experiments are required to confirm the efficiency of each function in the tool to support decision making, reduce decision error, and increase the ability of decision making.

7.3 Developing and evaluating de-biasing techniques by providing feedback, incentive, and structure complex in product development activities

De-biasing techniques in this experiment (Tanaiutchawoot, Bursac, Rapp, Albers & Heimicke, 2019) are developed without an additional tool. 3 techniques are developed, which is in the de-biasing type II and type III in the framework. These 3 techniques in Figure 7.52 are

1) providing social feedback to the decision makers
2) implementing incentive
3) structure choice complex.

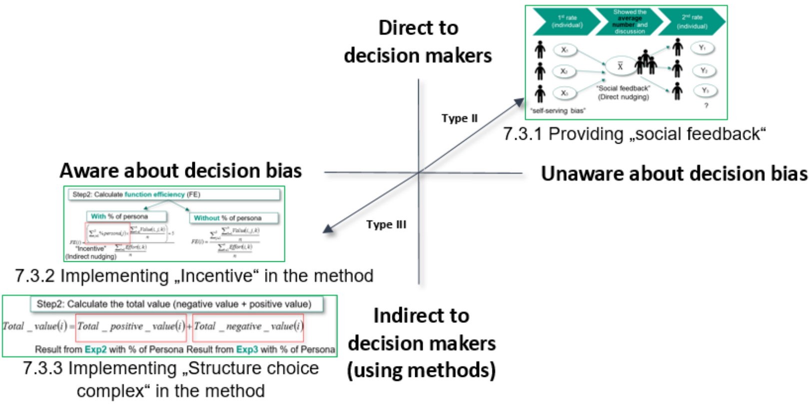


Figure 7.52: Three de-biasing techniques in type II and type III

These 3 techniques were implemented in one session of a creative workshop with an automotive company, which took place during the early stage of product development. This workshop aimed to develop concepts for a methodology supporting document that is possible to help members of a company solve everyday problems, enable effective and efficient access to methodological knowledge, and identify use cases and action requirements. Participants in this workshop are 7 company employees with different roles such as in engineering and as a project manager. An efficiency of de-biasing techniques that were implemented in this workshop were evaluated by comparing the results between a pre-study and a post-study.

The main objective of this session is to identify potential functions in the supporting tool based on 5 personas that have been created in the previous session to represent all members' character in the company. General activities in this session can be described into 4 steps:

Step 1 ***Creating functions in the supporting tool from the personal idea****:* the participants will create functions based on personal ideas without discussion, which takes around 20 minutes.

Step 2 ***Creating functions in the supporting tool from the website guidance***: 7 company's members and one researcher from the IPEK institute were separated into 4 groups and analyzed functions in different interesting websites. This step required 40 minutes

Step 3 ***Implementing ideas for the functions in the supporting tool using brainstorming method*****:** all created functions were revised and implemented more details by all participants using brainstorming.

Step 4 ***Evaluating functions regarding Personas' requirement and company's effort:*** all functions are classified and grouped to avoid redundant ideas. Then each function was evaluated from 0 to 5 regarding personas 'requirement and the company's effort.

In an evaluation of personas' requirement:
- "0" means the function has no benefit for that persona.
- "5" means the persona needs that function.

In an evaluation of effort:
- "0" means no effort is required from the company to develop this function.
- "5" means the company has to take a high effort to develop the function in the supporting tool.

Therefore, an efficient function in the supporting tool should have a high value in personas' requirements and a low value in a company's effort.

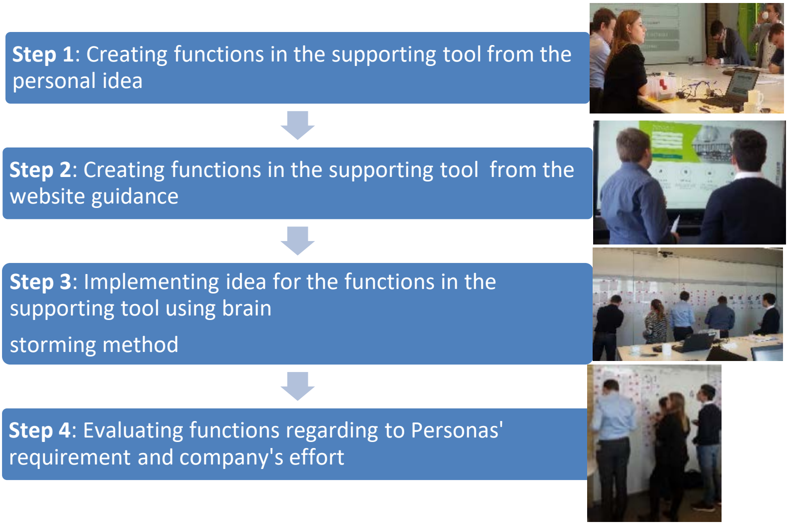


Figure 7.53: Four steps in this session of the creativity workshop

During the workshop in this session, 3 de-biasing techniques were implemented in creative activities to increase the efficiency of decision making and reduce the influence of decision biases. The first de-biasing technique, giving feedback to the decision maker, was implemented before creating the functions in the supporting tool. The other 2 de-biasing techniques were implemented in the process to evaluate functional efficiency. These 3 de-biasing techniques were explained and evaluated regarding 3 experiments in the following step.

7.3.1 Experiment 1: “giving feedback” (de-biasing technique type II)

At the beginning of the workshop in this session, 7 participants were asked to weight the percentage of 5 personas from the previous workshop. All of these personas represent the characteristics of members of the company. Each persona was rated in the percentage based on individual consideration. They approximated the number of members regarding the character in the persona using their experience and memory. After all, the persona was rated from all participants, results from each participant were averaged and showed to the participants to discuss the possibility of an average result regarding individual rating. In the discussion, each participant had a chance to explain and exchange information based on individual opinion. Then all participants were asked to rate the percentage of members regarding each

Persona again. Results of percentage in the first and the second round from each participant to 5 personas are shown in Table 7.7.

Table 7.7: Results of the percentage that represent the size of members in the company regarding each persona in the 1st and 2nd round of evaluation from 7 participants

Participant No.	Percentage (%) of members in the company									
	Persona 1		Persona 2		Persona 3		Persona 4		Persona 5	
	Round		Round		Round		Round		Round	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
1	25	30	35	35	5	5	10	10	25	20
2	30	30	20	25	30	25	10	15	10	5
3	25	25	45	45	10	5	5	5	15	20
4	35	35	40	35	5	5	5	5	15	20
5	20	25	35	35	10	10	15	10	20	20
6	15	30	50	35	5	5	5	5	25	25
7	20	25	30	30	20	15	10	10	20	20
Average	24	28	37	34	13	11	8	8	18	18
SD	6,22	3,5	9,15	5,62	8,8	7,7	3,5	3,5	5,1	5,8

Results in Table 7.7 shows that percentages from some persona were changed after the participants knew the average value of percentage in each persona and had a discussion in a group. This changing is then investigated to find the relationship among the rating in the first round, an average value of rating in the first round, and the rating in the second round.

$$\Delta 1(i,j) = \%in\ the\ 1^{st}\ round(i,j) - \frac{\sum_{j=1}^{7} \%\ in\ 1^{st}\ round(i,j)}{7} \quad 7.1$$

$$\Delta 2(i,j) = \%in\ the\ 1^{st}\ round(i,j) - \%in\ the\ 2^{nd}\ round(i,j) \quad 7.2$$

When i= number of participants, j= number of persona

Δ1 in Equation 7.1 represented the difference between the percentage from each participant in the first round and the average from 7 participants regarding each persona in the first round. Δ2 in Equation 7.2 represented the difference in the percentage from each persona in the first round and in the second round from each participant. The correlation of changing from the different reference points is shown in Figure 7.54.

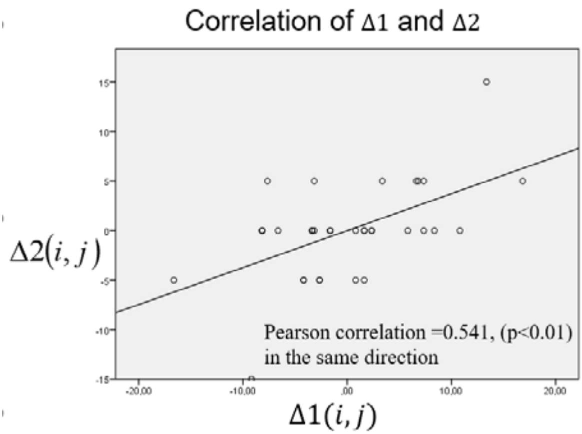


Figure 7.54: The correlation between the gap of the first rating from individual and the average rating from 7 participants (Δ1), and the gap of the first rating and the second rating from individual (Δ2)

Based on the statically analysis, there is a correlation between Δ1 and Δ2 in the same direction (PCC=0.541), $p<0.01$). This implies that the participants adapted the number of percentages in the second round to be close to the average number of percentages in the first round to reduce the gap between individual rating and group rating after getting the social feedback at the end of the first evaluation. This made the standard deviation of percentage in the 2nd round lower than the standard deviation of percentage in the 1st round of evaluation. From this result and analysis, the feedback can help the decision maker to be aware of personal decisions and have a chance to review his/her decision. Different levels of knowledge and experience can lead the decision maker to have a different level of self-serving bias, which sometimes is not noticeable by the decision maker. Social feedback is, therefore, another technique to de-bias self-serving bias by increasing the decision maker's awareness about his/her decision and group's decision.

Even feedback is a good strategy to avoid self-serving bias by increasing awareness of the group's decision, social feedback can also be a resource of bias regarding social bias. The decision maker tries to make a decision in the same direction that the group made, which is sometimes going in the wrong direction. Before applying the feedback for the de-biasing technique, side-effects of feedback should be acknowledged and analyzed.

7.3.2 Experiment 2: “incentive” (de-biasing technique type III)

The second experiment was done in the evaluation process after 107 functions in the supporting tool were defined in the creating functionality activity (step 1 to step 3 in Figure 7.53). Participants rated the score 1-5 to each function regarding the degree of persona’s satisfaction when that function is implemented in the tool. Because of a limited proceeding time, these functions and participants were divided into 2 groups to make an evaluation separately. 4 participants were assigned to make an evaluation of 54 functions in the first group, and others were assigned to make an evaluation of the rest functions in the second group. In the normal process, function efficiency is calculated from the level of the customer’s requirement and the company’s effort without considering the probability percentage of the customer or persona in the market. The value of the function is evaluated by focusing on the persona description and ignoring the priors or sample size, which leads the result to be biased from representativeness heuristic.

The process to calculate function efficiency is, therefore, improved by integrating the de-biasing technique in the calculation. An incentive is used to reduce the influence of representativeness heuristic in the evaluation process by implementing the percentage of persona to represent the sample size in each customer’s group. This is a concept idea of incentive that the decision should be made by considering on the customer’s group and requirements. Both types of calculations (with and without the percentage of persona) are shown in Equation 7.3 and Equation 7.4; the results from these two types of calculations are compared and shown in Figure 7.55.

- The calculation of function efficiency without % of persona

$$function\_efficiency(i) = \frac{\sum_{j=1}^{5}\frac{\sum_{k=1}^{n} Value(i,j,k)}{n}}{\frac{\sum_{k=1}^{n} Effort(i,k)}{n}} \qquad 7.3$$

- The calculation of function efficiency with % of persona (implementing de-biasing technique)

$$function\_efficiency(i) = \frac{\left(\sum_{j=1}^{5} \%of\ persona(j) \times \frac{\sum_{k=1}^{n} Value(i,j,k)}{n}\right) \div 5}{\frac{\sum_{k=1}^{n} Effort(i,k)}{n}} \qquad 7.4$$

When i=number of function, j=number of persona, k=number of a participant, n=amount of participant (4 in group 1 and 3 in group2)

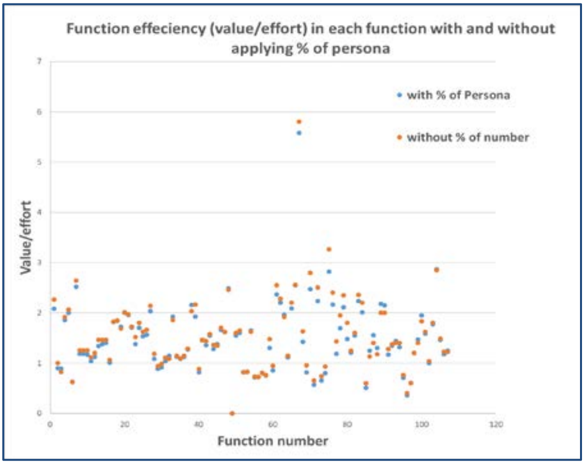


Figure 7.55: Results of function efficiency when calculating with the normal process (without % of persona) and with implementing the de-biasing technique in the process (with % of persona)

The results from 2 methods of calculation (with and without % of persona) show a significant difference (t105=-5.8, p<0.01), which means implementing the probability of persona regarding base rate in a real customer group affected the value of functional efficiency. Ignoring the base rate of customers then can lead to a wrong estimation of the function's value. However, this error caused by representativeness heuristic can be handled using incentive techniques.

After calculating the function efficiency, each function was grouped and categorized into 9 main groups based on a concept idea of each function to avoid redundant functions. These groups are general, community, design, help, individual, purification, sustainability, improvement, and assessment. Each main group was then separated in different sub-functions. Each function is represented by X.Y when X was the number of the main group, and Y was the number of sub-function. 3 groups of the evaluation were identified to classify functions based on the value of function efficiency, which is described in the following:

- Group A: $\frac{Value}{Effort} \geq 1$, Functions were certainly be implemented in the tools
- Group B: $1 > \frac{Value}{Effort} \geq 0.8$, Functions were discussed before being accepted or rejected
- Group C: $0.8 > \frac{value}{Effort}$, Functions were rejected

Results from the previous evaluation were classified as showing in Table 7.8. The red colour in the table shows a different result based on different method of calculation.

Table 7.8: Groups of function efficiency from the calculation with and without % of persona

No. Of Function	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**3.1**
With	A	B	C	C	A	A	A	A	C	B	A
Without	A	B	C	C	A	A	A	A	B	B	A
No. Of Function	**3.2**	**4.1**	**4.2**	**4.3**	**5.1**	**5.2**	**5.3**	**5.4**	**5.5**	**5.7**	**5.8**
With	A	A	B	A	A	B	A	C	A	A	A
Without	A	A	A	A	A	B	A	C	A	A	A
No. Of Function	**5.9**	**5.10**	**6.1**	**6.2**	**6.3**	**6.4**	**7.1**	**8.1**	**8.2**	**8.3**	**8.4**
With	A	A	A	A	A	A	C	A	A	C	B
Without	A	A	A	A	A	A	C	A	A	C	B
No. Of Function	**9.1**	**9.2**	**9.3**	**9.4**	**9.5**	**9.6**	**9.7**	**9.8**	**9.9**		
With	A	A	A	A	B	A	A	A	A		
Without	A	A	A	A	A	A	A	A	A		

Results of function number 2.4, 4.2 and 9.5 in Table 7.8 show the different group of function efficiency when calculating it using different techniques (with and without the % of persona). These results illustrate an overestimation by accepting an inefficient function when percentage of persona was not implemented in the calculation. Results in this table suggest that ignoring the probability of distribution caused by the representativeness heuristic can affect a wrong estimation, evaluation, and selection. The incentive technique, that concentrating on who uses, who chooses, who pays, and who profits, is a technique to reduce the influence of heuristic decision and bias in the method and increase the decision-making's effectiveness.

7.3.3 Experiment 3 “structure choice complex” (de-biasing technique type III)

Normally, functions are selected based on an evaluation in experiment 2 that relied only on persona satisfaction. That evaluation, however, could lead to the decision bias caused by the feature positive effect by focusing on only the positive side and ignoring the negative side even the negative side effects the result or solution. Based on this bias in the method, a structure choice complex was implemented to reduce the influence of this bias in an evaluation method, which is one of the de-biasing techniques in type III. The complexity of analysis is increasing by integrating the negative value of persona in the calculation of function value and use the total function value to be another criterion to evaluate the functions. The negative value was calculated from the level of dissatisfaction of a persona when the function was not implemented in the tool, which can also be rated from 0-5. The 0 value means the persona feels nothing when ignoring that function; the 5 value means the persona is extremely dissatisfied when ignoring that function. The positive and negative of function value were calculated based on Equation 7.5 and Equation 7.6, respectively. Then results from these 2 values were combined to find the total value in Equation 7.7.

$$Total\_positive\_value(i) = \frac{\sum_{j=1}^{5} \%\, of persona(j) \times \frac{\sum_{k=1}^{n} value(i,j,k)}{n}}{5} \qquad 7.5$$

$$Total\_negative\_value(i) = \frac{\sum_{j=1}^{5} \%\, of persona(j) \times \frac{\sum_{k=1}^{n} neg\_value(i,j,k)}{n}}{5} \qquad 7.6$$

$$Total\_value(i) = Total\_positive\_value(i) + Total\_negative\_value(i) \qquad 7.7$$

When i= number of functions, j= number of personas, k= number of participants, n=amount of participants (4 in group 1 and 3 in group2)

Results from the calculation of $Total\_value$ were separated into 3 levels, which are „Interesting“, „Good“, and „Important“. The description for each level was explained in the following:

- **In: Interesting** (function is *interesting* to be implemented in the tool): $Total\_value \geq 1$
- **Good** (function *should* be implemented in the tool): $1 > Total\_value \geq 0.8$
- **Im: Important** (function *must* be implemented in the tool): $0 > Total\_value$

Instead of considering only the function efficiency, the level of total function value is added in a consideration to increase the complexity of analysis to select functions in the tool. The decision maker, therefore, has more information to make a decision about rejecting or accepting the function. This technique helps the decision maker to broaden his/her perspective. Table 7.9 shows the evaluation for each function regarding to group of function efficiency and level of total_value. Each level of evaluation regarding these two methods are described in

Table 7.10.

Table 7.9: Group of function based on the group of function efficiency and the level of the total function value

No. of function	**1.1**	**1.2**	**1.3**	**1.4**	**1.5**	**2.1**	**2.2**	
Group	A	B	C	C	A	A	A	
Level	Im	Good	Good	Good	In	Good	Good	
No. of function	**2.3**	**2.4**	**2.5**	**3.1**	**3.2**	**4.1**	**4.2**	
Group	A	C	B	A	A	A	B	
Level	Good	Good	Good	Good	Good	Good	Good	
No.of function	**4.3**	**5.1**	**5.10**	**5.2**	**5.3**	**5.4**	**5.5**	
Group	A	A	A	B	A	C	A	
Level	Good	Good	In	In	In	Im	Good	
No.of function	**5.6**	**5.7**	**5.8**	**5.9**	**6.1**	**6.2**	**6.3**	
Group	A	A	A	A	A	A	A	
Level	Good	Good	Good	In	Good	Good	Good	
No.of function	**6.4**	**7.1**	**8.1**	**8.2**	**8.3**	**8.4**	**9.1**	
Group	A	C	A	A	C	B	A	
Level	Good	Im	Good	Good	Good	Im	Good	
No. of Function	**9.2**	**9.3**	**9.4**	**9.5**	**9.6**	**9.7**	**9.8**	**9.9**
Group	A	A	A	B	A	A	A	A
Level	Good	Good	In	Good	Good	Good	Good	Im

Table 7.10: The meaning of function regarding the group of function efficiency and the level of the total value

Group of function efficiency	Level of total_value	Meaning	Suggestion
A	Interesting	The function has high efficiency and is interesting for the customer	accept
	Good	The function has high efficiency and is good for the customer	accept
	Important	The function has high efficiency and is important for the customer	accept
B	Interesting	The function has normal efficient and is interesting for the customer	additional condition
	Good	The function has normal efficient and is good for the customer	additional condition
	Important	The function has normal efficient and is important for the customer	accept
C	Interesting	The function has low efficient but is interesting for the customer	reject
	Good	The function has low efficient but is good for the customer	reject
	Important	The function has low efficient but is important for the customer	analyze

The function in group A of function efficiency is usually accepted to be implemented in the tool. On the other hand, the function in group C of function efficiency is rejected. When analyzing the function with the level of the total value, some functions should not be rejected as showing in Function 5.4 and Function 7.1. The decision maker had to analyze more details before making the decision because those functions are important for the customer. On the other hand, some functions can be postponed to the next generation of product development even if they have high efficiency (in A group) but are not important (important level).

Adding the level of the total value in the evaluation to increase the choice complex can encourage the decision maker to be more cautious and effective in decision making. Moreover, the positive effect that leads the decision maker to be biased is reduced by the structure complex choice that was implemented in the method for evaluating the result.

7.3.4 Conclusion

Three de-biasing techniques in type II and type III showed their performance to avoid or reduce the influence of heuristic decisions and biases from the decision maker and methods. Giving feedback, incentive and structure choice complex is an effective technique to improve the heuristic decisions and reduce decision biases when defining and selecting concept ideas of product. However, people should consider the side-effect of these de-biasing techniques, which are possibly used to avoid the decision bias and also cause another bias.

7.4 Developing and evaluating pairwise-comparison technique to avoid the decision bias

The de-biasing technique in this experiment (Tanaiutchawoot, N., Bursac, N., Rapp, S., & Albers, A., 2019) is developed by modifying a method to present alternatives using the pairwise-comparison technique, which belongs to the de-biasing technique type VI as shown in Figure 7.56.

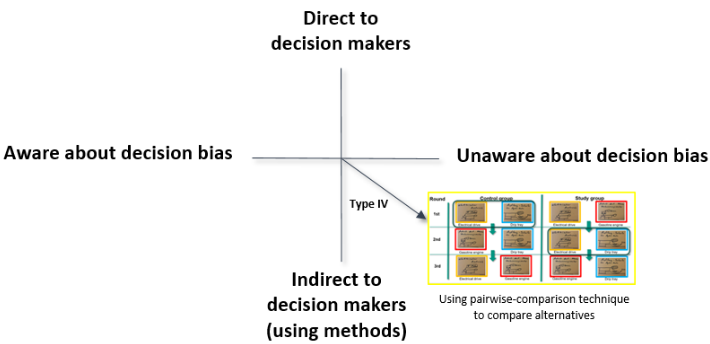


Figure 7.56: De-biasing in type IV using pairwise comparison

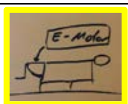
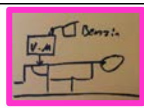
This experiment is designed to reduce the influence of the decoy effect in the idea selection for the next generation of apple peeler, which was illustrated in Section 4.

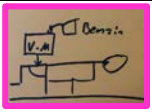
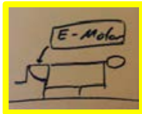
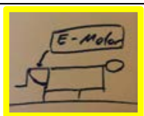
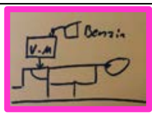
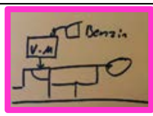
This bias happens when 3 alternatives are compared, and two alternatives are similar but have different qualities. The alternative that has a similar concept idea but is better in quality will have more focus and more frequently selected than the alternative which has a different concept idea but is also good in quality. From the experiment in Section 4 about the decoy effect, the resource of bias comes from the method to present alternatives. Therefore, this bias can be reduced by restructuring the method to present alternatives, which is the de-biasing technique type IV in the framework for applying the de-biasing technique in product development.

Processes in this experiment are similar to the experiment to investigate the decoy effect in the idea selection for the next generation of apple peelers. At the beginning of this experiment, all participants got information about the functions of the reference product (apple peeler), and the basic knowledge for product development such as the procedures to create and classify ideas for the next generation of apple peelers by watching the video. This video was the same video as showing to the participant in the previous experiment (in Section 4). Then the participants have to select the favorite idea for the next generation of apple peelers from 3 concept ideas that are “Electrical Driver”, “Drip Tray”, and “Gasoline Engine”. The electrical driver alternative and the drip tray alternative are assumed to have the same level of rational product idea because both of them focus on solving different problems in the reference product that were showed in the video. The gasoline alternative, on the other hand, is assumed to be a decoy alternative to encourage the participants to focus on the electrical driver alternative because of similar technical solutions but different levels of the quality ideas. The gasoline engine seems to be an irrational idea.

Instead of showing all 3 alternatives at the same time similar to the experiment in Section 4, these 3 alternatives were paired and presented to the participant in 3 sequences based on the pairwise-comparison technique as shown in Table 7.11.

Table 7.11: Sequences of comparison in the study group and the control group

Sequence	Control group		Study group	
1st	 Electrical Driver	 Drip Tray	 Electrical Driver	 Gasoline Engine

2nd	 Gasoline Engine	 Drip Tray	 Electrical Driver	 Drip Tray
3rd	 Electrical Driver	 Gasoline Engine	 Gasoline Engine	 Drip Tray

The objective of this technique is to reduce the influence of the decoy effect by presenting alternatives in pairs. Two alternatives are compared, and the favorite idea is selected each time. The idea that has been selected 2 times will represent the final selection or the absolute selection. An effect of this de-biasing technique is then evaluated by comparing the results from the control group and the study group that will get the different sequences of comparison.

Based on the assumption that comparing alternatives using the pairwise-comparison technique can reduce the influence of the decoy effect, the gasoline engine alternative should not be a possible influence on the decision maker when focusing on the electrical driver comparing between the electrical driver alternative and the drip tray alternative. In the control group, 2 reasonable ideas are presented in the first sequence to avoid influence from the gasoline engine alternative. The sequences in the 2nd and the 3rd comparison in this group have no meaning to investigate the influence of the decoy effect. These sequences can be converted. In the study group, the electrical driver alternative is compared to the gasoline alternative in the first round of comparison. Then the electrical driver alternative and the drip tray alternative are compared in the 2nd round of comparison to investigate the influence of the decoy alternative in the previous comparison. If the decoy alternative from the previous comparison can influence the decision maker to focus on the electrical driver alternative in the current comparison, the electrical driver will have higher chance to be selected than the drip tray alternative in the current information. This is the assumption for the investigation in this experiment. The comparison in the 2nd sequence is nearly similar to the experiment in Section 4 that all 3 alternatives were presented in the same sequence. Therefore, the selection behavior in the study group and the control group in this experiment (using pairwise-comparison technique) has a similar structure as the experiment in Section 4 (presenting all alternatives in the same sequence) that aimed to investigate the decoy effect in the idea selection for the next generation of apple peeler.

Before starting this experiment in the main group of participants, 20 students (10 students in the control group and 10 students in the study group) were asked to participate in this experiment to test the experiment and get some feedback. The participants in the main study are the 4th semester students in mechanical engineering (n=497). They are randomly separated into the control group (n=248) and the study group (n=249). The experiment proceeded via email with separating link of the questionnaire in the control group and the study group. This experiment was expired 1 week after that. The completed responds from both groups are then analyzed, which come from 61 participants in the control group and 62 participants in the study group. Results from this experiment are analyzed in answers of 3 questions:

1) Can the decoy effect influence decision-making behavior when using the pairwise-comparison technique to propose an alternative? This question will be answered by comparing the results in the first sequence of comparison in the control group and the second sequence in the study group.
2) How can the sequences in alternative pairs influence the absolute results of the selection? The answer can be found when comparing the absolute selection between the control group and the study group
3) How can the structure alternatives influence decision making to compare alternatives and select a final solution? The result from the experiment in Section 4, which aims to investigate the decoy effect in the idea selection for the next generation of apple peelers is compared to the absolute selection from this experiment to answer this question.

7.4.1 Investigate a decoy effect in a pairwise comparison method based on the sequences of comparison

Results from both groups are summarized in the percentage form within rounds and groups as shown in Table 7.12. Then the results from the first comparison in the control group and the second comparison in the study group are compared and shown in Figure 7.57.

Table 7.12: Results of solution selection in each sequence of comparison using the pairwise-comparison technique in the control group and the study group

Sequence		**Selection (%)**			
		Control group (N=61)		**Study group (N=62)**	
1st	alternative	Electrical Driver	Drip Tray	Electrical Driver	Gasoline Engine
	%	60.66	39.34	87.10	12.90
2nd	alternative	Gasoline Engine	Drip Tray	Electrical Driver	Drip Tray

	%	27.87	72.13	43.55	56.45
3rd	alternative	Electrical Driver	Gasoline Engine	Gasoline Engine	Drip Tray
	%	81.97	18.03	12.90	87.10

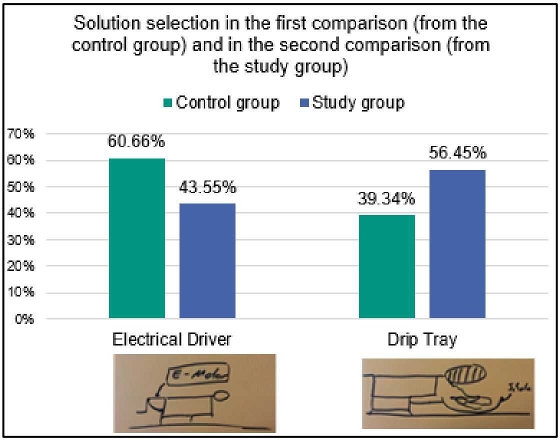


Figure 7.57: the result of solution selection in the first comparison from the control group and in the second comparison from the study group

The result when comparing the electrical driver alternative and the drip tray alternative in the control group and in the study group showed that 60.66% of participants in the control group selected the electrical driver alternative and the rest selected the drip tray alternative. On the other hand, most participants in the study group (56.45%) selected the drip tray alternative. Other participants in this group selected the electrical driver alternative. Results of selection behavior from both groups are different regarding the statistical analysis ($p<0.05$).

Even selection behavior from both groups are different, the result from the study group does not show an influence of decoy effect when comparing and selecting the alternative in the second round. On the other word, proposing the decoy alternative (gasoline engine) with the similar but better idea (electrical driver) before comparing 2 rational alternatives (electrical driver and drip tray) in a current comparison does not influence the decision making to select the similar but better idea (electrical driver) in the current comparison.

The result from this comparison can be claimed that comparing alternatives using the pairwise-comparison technique that is aimed to be the de-biasing technique can reduce the decision bias caused by the decoy effect. However, the difference in selection behavior between 2 groups regarding the pairwise-comparison technique should be further investigated.

7.4.2 Investigate results of absolute selection when comparing alternatives with different pairs and sequences

Results of absolute selection in the control group and the study group are compared to investigate the influence of sequences to present alternatives in the pairwise-comparison technique to the final result. Only results from 60 participants in the control group and the study group are used to compare the result because results from other participants show the inconsistency of selection by selecting all 3 alternatives but in a different sequence. These results are calculated in the percentage and shown in Figure 7.58.

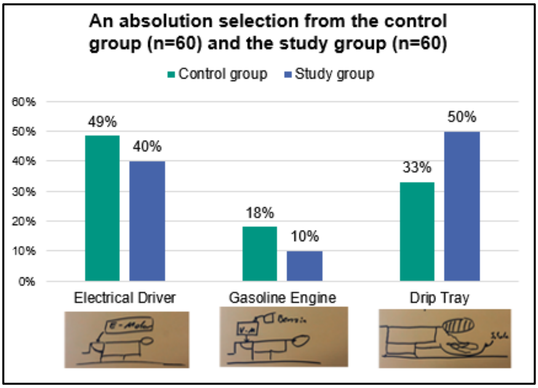


Figure 7.58: The result of absolution selection from the control group and the study group using the pairwise-comparison technique

In the control group, 49% of participants selected the electrical driver alternative, and 33% of participants selected the drip tray alternative. The rest of the participants in this group selected the gasoline engine alternative. However, 50% of participants in the study group selected the drip tray alternative. 40% of participants in the same group selected the electrical driver alternative; other participants selected the gasoline engine alternative. Results of absolute selection from both groups do not show a significant difference (p=0.231). That means different sequences to propose alternatives do not influence the final result of selection. This result also confirms the previous conclusion that using the pairwise comparison technique to compare alternatives can reduce the influence of decision bias caused by the decoy effect. Therefore, comparing 3 alternatives in pairs can reduce the influence of decision bias from the decoy effect and increase the efficiency of decision making.

7.4.3 Investigate an influence of decoy effect when presenting all alternatives in the same sequence and presenting alternatives in pairs

Results from the experiment in Section 4 and from this experiment are compared in Figure 7.59 to investigate the decision behavior when using different techniques to present alternatives.

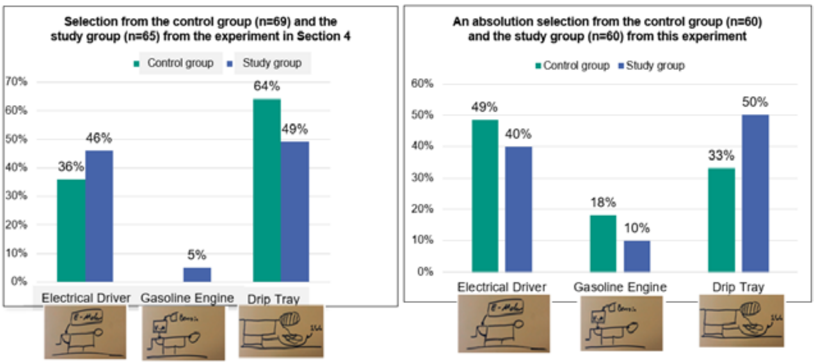


Figure 7.59: Results of the final selection between the control group and the study group from the experiment in Section 4 (investigating the decoy effect in the idea selection) and from this experiment (implementing the de-biasing technique to reduce the influence of heuristic decision)

Results from both experiments show different behavior of decision making in the idea selection phase. From the previous experiment, participants in the study group preferred the electrical driver more than the participants in the control group. When comparing the results from this experiment, participants in the study group preferred the electrical driver lower than the participants in the control group. Results in the study groups from the previous experiment and this experiment also confirm that comparing alternatives using the pairwise-comparison technique can reduce the influence of decoy effect even a similar but lower quality is proposed and compared with another 2 alternatives. Another interesting result is a chance that the participants selected the senseless alternative or decoy alternative is increasing when using the pairwise comparison technique to compare alternatives and select the solution. This result can be a clue to show that using pairwise comparison to compare alternatives and select the solution can lead to the decision error, which is possibly caused by other types of biases. This side-effect from the pairwise-comparison technique, therefore, should be further investigated and analyzed before being applied to support decision making.

7.4.4 Conclusion

This experiment shows an example of de-biasing technique type IV in product development for reducing a decision bias caused by the decoy effect during solution selection for the next generation of apple peelers. The decision bias can be reduced by changing a method to present an alternative. All contents of alternatives are still the same. Therefore, comparing alternatives using the pairwise comparison technique or the binary comparison can be one of the efficient de-biasing techniques to avoid or reduce the decision biases in product development. However, this technique can also induce other types of biases such as status-quo bias that was shown in Experiment 3 in Section 5. Therefore, the decision behaviour when using this method should be further investigated.

7.5 Developing and evaluating a random algorithm to reduce the appearance of anchoring heuristic when creating an influence matrix

As showing in Section 7.4, restructuring choices can change decision behavior such as reducing decision bias from the decoy effect. This experiment shows another example of the de-biasing technique using a random algorithm, which is the de-biasing technique type IV in the framework (in Figure 7.60).

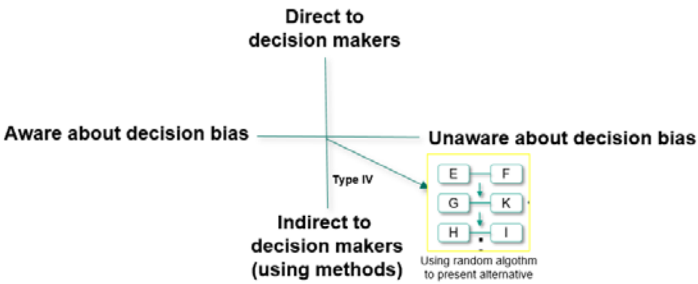


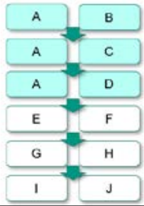
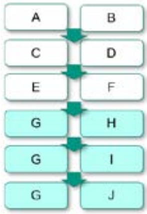
Figure 7.60: De-biasing technique type IV using a random algorithm

7.5.1 Using a random algorithm to present influence factors when evaluating influence values to avoid anchoring and adjustment heuristic

The random algorithm was used instead of a sequential algorithm to present influence factors to create an influence matrix in the scenario method. This method was shown in Experiment 5.4 in Section 5, which showed the anchoring bias in the sequential algorithm rather than in the random algorithm when evaluating influence values in each pair of influence factors in both groups. The analysis was done based on the result in Experiment 5.4, which is summarized in Table 7.13.

Table 7.13: Summarize the result from the Experiment 5.4 in Section 5 that shows the de-biasing technique using the random algorithm

Group of participants	Algorithm to present the influence factors	An average gap of influence value		Average time (min)	
		When using the *sequence* algorithm	When using the *random* algorithm	with the *sequence* algorithm	with the *random* algorithm

1	Start with the sequence algorithm and then the random algorithm		1.30	1.31	10.26	10.62
2	Start with the random algorithm and then the sequence algorithm		1.08	1.43	7.05	8.60

Results from Table 7.13 show the average gaps of influence value when proposing the influence factors using the sequential algorithm is higher than when using the random algorithm in both groups, especially in the second group. In other words, the decision makers tried to adjust the next influence value based on the initial influence value when one influence factor was fixed and the other influence factor was changed. This adjustment was also in a small number to avoid deviating from the baseline or the initial value. In the random algorithm, an influence from anchoring number is decreasing because both influence factors were changed. The decision makers had to rethink the relationship between two influence factors without the initial value. That means the random algorithm to propose the influence factors can reduce the influence of the anchoring and adjustment heuristic by encouraging the decision makers to rethink the contents from each pair instead of focusing on the initial value or the previous evaluation. This analysis is supported by the proceeding time to finish this experiment. In the first group, the average time to evaluate the influence values when using the sequential algorithm and the random algorithm is 10.26 minutes and 10.62 minutes, respectively. At the same time, the average time to evaluate the influence values in the second group is 7.05 minutes in the sequential algorithm and 8.60 minutes in the random algorithm. This means participants in both groups spent time to evaluate influence values in the sequential algorithm more than in the random algorithm. Proposing influence factors using the sequential algorithm can support the decision makers to make easier decisions. However, time between both groups are not significantly different. Moreover, results from interviews showed that the decision makers prefer to make an evaluation using the sequential algorithm to propose influence factors rather than using the random algorithm because they can make a current decision based on the previous decision. Using the random algorithm to present influence factors leads the decision maker to rethink about the influence factors, which needs more time than using the sequential algorithm to make a decision.

Another interesting point in the results from both groups is the amount of difference gap values between the sequential algorithm and the random algorithm from group 1 and group 2. Average gaps of influence values in the first group when using the sequential algorithm and then random algorithm to propose influence factors are nearly close with 1.30 and 1.31, respectively. These average gaps are more different in the second group when influence factors were proposed using the random algorithm and then the sequential algorithm with 1.08 and 1.43. Results from both groups imply that proposing the random algorithm before proposing the sequential algorithm can reduce the influence of anchoring and adjustment heuristic better than proposing the sequential algorithm before proposing the random algorithm.

Even random algorithm can reduce the influence of anchoring bias by encouraging the decision makers to rethink about the contents in each alternative, this method will be working if the decision makers are trained at the beginning as showing in group 2. This technique shows low success if the decision makers are already accustomed to the anchoring and adjustment heuristic shown in group 1. This result supports a finding from the literature that the anchoring and adjustment heuristic is one of many heuristics that is difficult to avoid because all information around the decision maker can be used for the reference point or the initial information. Ignoring surrounding information is rarely possible in decision making.

7.5.2 Conclusion

De-biasing type IV in the de-biasing framework, restructuring choice structure, can be used to reduce the influence of anchoring and adjustment heuristic that causes the decision bias from an environment or initial information. Encouraging the decision maker to rethink the alternatives during an evaluation can reduce the influence of anchoring and adjustment based on the initial or previous information.

However, avoiding this type of heuristics and biases is difficult. Even the decision makers are aware of this heuristic. They cannot control or avoid this heuristic and bias in their decision. This is another challenge in the field of psychology- to handle decision making when encountering this type of heuristic decisions and biases.

7.6 Conclusion

Five experiments in this chapter show the different types of de-biasing techniques that can be used in different forms and different decision situations in product development. De-biasing type I by directly transferring the knowledge to the decision maker requires decision maker's awareness about the heuristic decisions and biases. Materials to transfer the knowledge can be video, poster or checklist. Debiasing type II also affects directly to the decision maker but does not require decision maker's awareness. De-biasing technique such as providing feedback in the decision tool is an example of this type of de-biasing. De-biasing technique type III requires also decision maker's awareness about the heuristic decisions and biases. However, techniques in this type are implemented in the design method such as rating score. This is another way to improve the design method to provide a better solution. The last type of de-biasing technique is called de-biasing type IV. These techniques that are implemented in the design methods can handle the heuristic decisions and biases without requiring an awareness from the decision maker. Hence, decision bias can be reduced, even the decision maker is unaware of the types of bias in decision making. In other words, decision bias can be handled whether the decision makers are aware of it or not.

However, some de-biasing techniques have a side effect, which can be used to reduce one heuristic decision and bias and also convince the appearance of other decision biases as showing in Experiment 7.3 and Experiment 7.4. Therefore, decision makers should be aware of these influence factors before applying de-biasing techniques to avoid heuristic decisions and biases.

Results from many experiments in this research indicate that heuristic decisions and biases cannot be definitely avoided during making decisions in the product development process. Increasing the performance of decision making by inducing them to one direction cannot be used in this field because the correct direction of the decision cannot be defined and described. Therefore, understanding the influence of decision heuristics and biases in decision making is the best way to reduce decision errors. The decision makers then have a chance to accept or reject the result that is influenced by heuristic decisions and biases. However, findings of this research show a variety of possibilities to deal with the heuristic decisions and biases. If the decision maker recognizes some heuristic decisions and biases in the process of product development, different types of de-biasing technique from the proposal in this thesis can be one alternative to handle the decision errors by adapting an idea of de-biasing to be suitable for each specific situation.

8 Summary and Outlook

This research shows some examples of heuristic decisions and biases in activities of product development. These biases can appear in the whole product development in spite of using design methods to support and assist decision making. Three main sources that lead the decision to be biased are decision makers, environments, and choice structures as explained in Section 4. 4 experiments in Section 5 were designed to proof possible situations of these 3 relevant components. An appearance of heuristic decisions and biases in the product profile selection from each experiment can be used to answer the first question in the research question.

The second question was answer in Section 6. Heuristic decisions and biases can be avoided and reduced using different types of de-biasing techniques. Most techniques from other fields aim to avoid the mistake by leading the decision makers in the correct direction using nudging strategy. Different frameworks to apply nudging strategy were used to design the de-biasing framework in product development. Ideas in each framework cannot be applied to handle decision biases in product development because the correct decision cannot be defined at that time. Instead of pointing out the correct decision to the decision maker, helping decision maker to avoid traps or wrong directions is the main idea to deal with heuristic decisions and biases in product development.

Four types of de-biasing techniques based on the framework were presented in this research to deal with heuristic decisions and biases in product development.

- De-biasing technique type I: the de-biasing technique is applied ***directly to the decision maker*** that aims to ***raise a decision maker's awareness*** about heuristic decisions and biases.

- De-biasing technique type II: the de-biasing technique is also applied ***directly to the decision maker*** but ***does not require a decision maker's awareness*** about heuristic decisions and biases. This technique aims to remind the decision maker about his/her previous decision

- De-biasing technique type III: the de-biasing technique is ***applied in the method*** and ***raise a decision maker's awareness*** about heuristic decisions and biases during using the method to support decision making.

- De-biasing technique type IV: the de-biasing technique is applied ***in the method*** and ***does not require a decision maker's awareness*** about heuristic decisions and biases.

The de-biasing framework in Section 6 and examples of de-biasing techniques in each type in Section 7 then answer the third question.

Based on the results from Section 4 to Section 7, three research questions in Section 3 are answered and described. Even though these techniques are proposed to handle or control heuristic decisions and biases in product development, they can also cause an appearance of other heuristic decisions and biases. This is a side effect of de-biasing techniques that should be understood before applying them. In the researcher's opinion, heuristic decisions and biases cannot be definitely avoided. The best way to reduce a decision error caused by heuristic decisions and biases is to understand and be aware of it when making a decision. The decision maker, therefore, has a chance to accept or reject that decision.

Results from this research, however, are only the beginning first step to show and understand the influence of heuristic decisions and biases in the product development process. Within this research, the researcher gained and collected information from many resouces such as literatures, observation in the real situation and experiments in Live Labs with students in the faculty of Engineering and engineering in the company partners as shown in Chapter 4. All of this information lead to asssmptions about an appearance of heuristic decision in different activities of product development. These assumptions were evaluated in Chapter 5 with examples from four experiments. The concept idea to handle these biases were then investigated and proposed based on knowledge from other fields that mainly relied on the nudging technique as shown in Chapter 6. At the end of this research, examples of studies based on the concept idea in Chapter 6 were proposed and evaluated in different design experiments with students in the university and employees in the company partners as shown in Chapter 7. Results from these studies showed an ability of techniques to handle heuristic decisions and biases in activities of product development. Even though these experiments were design in variety environment and situations of decision making that closed to the practical situations, there are many limitation and insufficient information such as number of participants, procedure time, and consistency.

Therefore, this research should be further investigated in details to increase the efficiency of decision making and decrease decision errors. The examples are different biases in different activities of product development and different roles of decision makers, influences of heuristic decisions and biases to the new product or the next product generation, and the potential tool to handle these biases in different activities. Even though many results from this research require more evaluation and analysis, most of them came from the experiment in the real situation of product development. This is a positive feedback to show the effective of techniques in this research to handle to the heuristic decisions and biases in product development. Therefore, each company can modify ideas and techniques to improve decision making in product development based on their environments and situations.

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Appendix A

Table A.1 1: Heuristic decisions and biases that are caused by the decision maker (Continue from Table 4.3)

No	Biases	Description
1	Absent-minded-ness	The subject experiences low levels of attention and frequent distraction because (1 low level of attention, 2 focus on one spot and forget surrounding, 3 unwarranted distraction of attention from the object of focus by irrelevant thoughts or environment event)
2	Ambiguity effect	The tendency to avoid options for which missing information makes the probability seem "unknown".
3	Attentional bias	The tendency of our perception to be affected by our recurring thoughts.
4	Automation bias	The tendency to depend excessively on automated systems which can lead to erroneous automated information overriding correct decisions.
5	Availability cascade	A self-reinforcing process in which a collective belief gains more and more plausibility through its increasing repetition in public discourse (or "repeat something long enough and it will become true").
6	Backfire effect	The reaction to disconfirming evidence by strengthening one's previous beliefs. cf. Continued influence effect.
7	Belief bias	An effect where someone's evaluation of the logical strength of an argument is biased by the believability of the conclusion.
8	Ben Franklin effect	A person who has performed a favor for someone is more likely to do another favor for that person than they would be if they had *received* a favor from that person.
9	Bias blind spot	The tendency to see oneself as less biased than other people, or to be able to identify more cognitive biases in others than in oneself.
10	Congruence bias	The tendency to test hypotheses exclusively through direct testing, instead of testing possible alternative hypotheses.
11	Conjunction fallacy	The tendency to assume that specific conditions are more probable than general ones.
12	Continued influence effect	The tendency to believe previously learned misinformation even after it has been corrected. Misinformation can still influence inferences one generates after a correction has occurred.cf. *Backfire effect*

Appendix A

No	Biases	Description
13	cryptomnesia	Individuals mistakenly believe that they are the original generators of the though
14	Declinism	The predisposition to view the past favorably (rosy retrospection) and future negatively.
15	Dunning–Kruger effect	The tendency for unskilled individuals to overestimate their own ability and the tendency for experts to underestimate their own ability.
16	Duration neglect	The neglect of the duration of an episode in determining its value
17	Empathy gap	The tendency to underestimate the influence or strength of feelings, in either oneself or others.
18	Endowment effect	The tendency for people to demand much more to give up an object than they would be willing to pay to acquire it.
19	Exaggerated expectation	Based on the estimates, real-world evidence turns out to be less extreme than our expectations (conditionally inverse of the conservatism bias).
20	Experimenter's or expectation bias	The tendency for experimenters to believe, certify, and publish data that agree with their expectations for the outcome of an experiment, and to disbelieve, discard, or downgrade the corresponding weightings for data that appear to conflict with those expectations.
21	Fading affect bias	Psychology phenomena in which information regarding negative emotions tends to forgotten more quickly than associated with pleasant emotions
22	False memory	Identify and interpersonal relationships are strongly centered around a memory of an experience that did not actually take place
23	Focusing effect	The tendency to place too much importance on one aspect of an event.
24	Forer effect or Barnum effect	The observation that individuals will give high accuracy ratings to descriptions of their personality that supposedly are tailored specifically for them, but are in fact vague and general enough to apply to a wide range of people. This effect can provide a partial explanation for the widespread acceptance of some beliefs and practices, such as astrology, fortune-telling, graphology, and some types of personality tests.
25	Google effect	The tendency to forget information that can be found readily online by using internet search engines
26	Hostile attribution bias	The "hostile attribution bias" is the tendency to interpret others' behaviors as having hostile intent, even when the behavior is ambiguous or benign.
27	Illusion of validity	The belief that our judgments are accurate, especially when available information is consistent or inter-correlated.

No	Biases	Description
28	Impact bias	The tendency to overestimate the length or the intensity of the impact of future feeling states.
29	Law of the instrument	An over-reliance on a familiar tool or methods, ignoring or under-valuing alternative approaches. "If all you have is a hammer, everything looks like a nail."
30	Leveling and sharpening	leveling: hear or remember something and drop details which do not fit cognitive assumptions; sharpening: hear or remember something and emphasize details which fit cognitive assumptions
31	Levels of processing effect	Memory recall of stimuli as a function of the depth of mental processing (deeper levels of analysis produce longer-lasting and stronger memory than shallow levels)
32	Memory inhibition	The ability not to remember irrelevant information (inhibit irrelevant information)
33	Misinformation effect (false memory, suggestibility)	Person's recall of episodic memories becomes less accurate because of post-event information
34	Mere exposure effect	The tendency to express undue liking for things merely because of familiarity with them.
35	Moral credential effect	The tendency of a track record of non-prejudice to increase subsequent prejudice.
36	Negativity bias or Negativity effect	The psychological phenomenon by which humans have a greater recall of unpleasant memories compared with positive memories. (see also actor-observer bias, group attribution error, positivity effect, and negativity effect).
37	Normalcy bias	The refusal to plan for, or react to, a disaster which has never happened before.
38	Not invented here	Aversion to contact with or use of products, research, standards, or knowledge developed outside a group. Related to IKEA effect.
39	Observer-expectancy effect	When a researcher expects a given result and therefore unconsciously manipulates an experiment or misinterprets data in order to find it (see also subject-expectancy effect).
40	Ostrich effect	Ignoring an obvious (negative) situation.
41	Outcome bias	The tendency to judge a decision by its eventual outcome instead of based on the quality of the decision at the time it was made.
42	peak-end rule	Judge an experience largely based on how they felt at the first peak and at the end, rather than average every moment of the experience no matter the experience is pleasant or unpleasant
43	Pessimism bias	The tendency for some people, especially those suffering from depression, to overestimate the likelihood of negative things happening to them.

Appendix A

No	Biases	Description
44	Post-purchase rationalization	The tendency to persuade oneself through rational argument that a purchase was good value.
45	prejudices	Unfavorable opinion or feeling formed beforehand or without knowledge, thought or reason
46	Pro-innovation bias	The tendency to have an excessive optimism towards an invention or innovation's usefulness throughout society, while often failing to identify its limitations and weaknesses.
47	Reactance	The urge to do the opposite of what someone wants you to do out of a need to resist a perceived attempt to constrain your freedom of choice (see also Reverse psychology).
48	Restraint bias	The tendency to overestimate one's ability to show restraint in the face of temptation.
49	Selective perception	The tendency for expectations to affect perception.
50	Semmelweis reflex	The tendency to reject new evidence that contradicts a paradigm.
51	Sexual over perception bias / sexual under perception bias	The tendency to over-/underestimate the sexual interest of another person in oneself.
52	Social comparison bias	The tendency, when making decisions, to favor potential candidates who don't compete with one's own particular strengths.
53	Social desirability bias	The tendency to over-report socially desirable characteristics or behaviors in oneself and under-report socially undesirable characteristics or behaviors.
54	Stereotyping	Expecting a member of a group to have certain characteristics without having actual information about that individual.
55	Subadditivity effect	The tendency to judge the probability of the whole to be less than the probabilities of the parts.
56	Subjective validation	The perception that something is true if a subject's belief demands it to be true. It also assigns perceived connections between coincidences.
57	suggestibility (related to misinformation effect, false memory)	Quality of being inclined to accept and act on the suggestions of others where false but plausible information is given and one fills the gaps in certain memories with false information when recalling moment (person memory the event conforms to the repeated message)
58	Tip of the tongue phenomenon	Failing to retrieve a word from memory, combined with partial recall and the feeling that retrieval is imminent
59	Well traveled road effect	Underestimation of the duration taken to traverse oft-traveled routes and overestimation of the duration taken to traverse less familiar routes.

Table A.2: Heuristic decisions and biases that are caused by the environment (Continue from Table 4.4)

No	Biases	Description
1	Anthropocentric thinking	The tendency to use human analogies as a basis for reasoning about other, less familiar, biological phenomena.
2	Base rate fallacy or Base rate neglect	The tendency to ignore base rate information (generic, general information) and focus on specific information (information only pertaining to a certain case).
3	Berkson's paradox	The tendency to misinterpret statistical experiments involving conditional probabilities.
4	Cheerleader effect	The tendency for people to appear more attractive in a group than in isolation.
5	Clustering illusion	The tendency to overestimate the importance of small runs, streaks, or clusters in large samples of random data (that is, seeing phantom patterns).
6	Contrast effect	The enhancement or reduction of a certain stimulus' perception when compared with a recently observed, contrasting object.
7	Courtesy bias	The tendency to give an opinion that is more socially correct than one's true opinion, so as to avoid offending anyone.
8	Curse of knowledge	When better-informed people find it extremely difficult to think about problems from the perspective of lesser-informed people.
9	Functional fixedness	Limits a person to using an object only in the way it is traditionally used.
10	Gambler's fallacy	The tendency to think that future probabilities are altered by past events when in reality they are unchanged. The fallacy arises from an erroneous conceptualization of the law of large numbers. For example, "I've flipped heads with this coin five times consecutively, so the chance of tails coming out on the sixth flip is much greater than heads."
11	Hindsight bias	Sometimes called the "I-knew-it-all-along" effect, the tendency to see past events as being predictable at the time those events happened.
12	Hot-hand fallacy	The "hot-hand fallacy" (also known as the "hot hand phenomenon" or "hot hand") is the fallacious belief that a person who has experienced success with a random event has a greater chance of further success in additional attempts.
13	Hyperbolic discounting	Discounting is the tendency for people to have a stronger preference for more immediate payoffs relative to later payoffs. Hyperbolic discounting leads to choices that are inconsistent over time – people make choices today that their future selves would prefer not to have made, despite

No	Biases	Description
		using the same reasoning.[47] Also known as current moment bias, present-bias, and related to Dynamic inconsistency.
14	Identifiable victim effect	The tendency to respond more strongly to a single identified person at risk than to a large group of people at risk.
15	Implicit stereotypes	Unconscious attribution of particular qualities to a member of a certain social group (influenced by experience, race, gender)
16	Implicit associations	automatic association between mental representations of objects (concepts) in memory
17	Insensitivity to sample size	The tendency to under-expect variation in small samples.
18	Irrational escalation	The phenomenon where people justify increased investment in a decision, based on the cumulative prior investment, despite new evidence suggesting that the decision was probably wrong. Also known as the sunk cost fallacy.
19	Look-elsewhere effect	An apparently statistically significant observation may have actually arisen by chance because of the size of the parameter space to be searched.
20	Money illusion	The tendency to concentrate on the nominal value (face value) of money rather than its value in terms of purchasing power.
21	Neglect of probability	The tendency to completely disregard probability when making a decision under uncertainty.
22	next-in-line effect	people being unable to recall information concerning events immediately preceding their turn to perform
23	Pareidolia	A vague and random stimulus (often an image or sound) is perceived as significant, e.g., seeing images of animals or faces in clouds, the man in the moon, and hearing non-existent hidden messages on records played in reverse.
24	Projection bias	The tendency to overestimate how much our future selves share one's current preferences, thoughts, and values, thus leading to sub-optimal choices.
25	Reactive devaluation	Devaluing proposals only because they purportedly originated with an adversary.
26	Recency illusion	The illusion that a word or language usage is a recent innovation when it is, in fact, long-established (see also frequency illusion).
27	Regressive bias	A certain state of mind wherein high values and high likelihoods are overestimated while low values and low likelihoods are underestimated.

No	Biases	Description
28	Risk compensation / Peltzman effect	The tendency to take greater risks when perceived safety increases.
29	source confusion	An attribute has seen indifferent people's account of the same event after hearing people speak about the situation (ex. Witness hear something and tell other people in a different way)
30	spacing effect	learning is greater when studying is spread out over time, as opposed to studying the same amount of content in a single session
31	Surrogation	Losing sight of the strategic construct that a measure is intended to represent, and subsequently acting as though the measure is the construct of interest.
32	Survivorship bias	Concentrating on the people or things that "survived" some process and inadvertently overlooking those that didn't because of their lack of visibility.
33	Testing effect	long-term memory is increased when some of the learning period is devoted to retrieving the to-be-remembered information through testing with proper feedback (memory stimulus by testing)
34	Third-person effect	The belief that mass communicated media messages have a greater effect on others than on themselves.
35	Triviality / Parkinson's Law of	The tendency to give disproportionate weight to trivial issues. Also known as bikeshedding, this bias explains why an organization may avoid specialized or complex subjects, such as the design of a nuclear reactor, and instead focus on something easy to grasp or rewarding to the average participant, such as the design of an adjacent bike shed.
36	"Women are wonderful" effect	A tendency to associate more positive attributes with women than with men.
37	Zero-risk bias	Preference for reducing a small risk to zero over a greater reduction in a larger risk.
38	Zero-sum bias	A bias whereby a situation is incorrectly perceived to be like a zero-sum game (i.e., one person gains at the expense of another).

Table A.3: Heuristic decisions and biases that are caused by the choice structure (Continue from Table 4.3)

No	Biases	Description
1	Choice-supportive bias	The tendency to remember one's choices as better than they actually were.
2	Decoy effect	Preferences for either option A or B change in favor of option B when option C is presented, which is completely dominated by option B (inferior in all respects) and partially dominated by option A.
3	Default effect	When given a choice between several options, the tendency to favor the default one.
4	Denomination effect	The tendency to spend more money when it is denominated in small amounts (e.g., coins) rather than large amounts (e.g., bills).[34]
5	Disposition effect	The tendency to sell an asset that has accumulated in value and resist selling an asset that has declined in value.
6	Distinction bias	The tendency to view two options as more dissimilar when evaluating them simultaneously than when evaluating them separately.
7	Frequency illusion	The illusion in which a word, a name, or other things that has recently come to one's attention suddenly seems to appear with improbable frequency shortly afterward (not to be confused with the recency illusion or selection bias).[41] This illusion is sometimes referred to as the Baader-Meinhof phenomenon.[42]
8	Illusory truth effect	A tendency to believe that a statement is true if it is easier to process, or if it has been stated multiple times, regardless of its actual veracity. These are specific cases of truthiness.
9	Less-is-better effect	The tendency to prefer a smaller set to a larger set judged separately, but not jointly.
10	list-length effect	The finding that recognition performance for a shortlist is superior to that for a long list
11	modality effect	The term used to refer to how learner performance depends on the presentation mode of studied items
12	negativity bias (related to lose aversion)	Even when of equality intensity, things of a more negative nature have a greater effect on one's psychological state and processes than do neutral or positive things

No	Biases	Description
13	Omission bias	The tendency to judge harmful actions as worse, or less moral, than equally harmful omissions (inactions)
14	part-list cueing effect	Re-exposure of a subset of learned material as a retrieval cue can impair recall of the remaining material
15	primary effect	Recalling information presented first better than information presented later on
16	Pseudocertainty effect	The tendency to make risk-averse choices if the expected outcome is positive, but make risk-seeking choices to avoid negative outcomes.
17	recency effect	Most recently presented items or experiences will most likely be remembered best
18	Rhyme as reason effect	Rhyming statements are perceived as more truthful. A famous example being used in the O.J Simpson trial with the defense's use of the phrase "If the gloves don't fit, then you must acquit."
19	serial position effect (serial recall effect)	The tendency of a person to recall the first and last items in a series best, and the middle items worse
20	suffix effect	Selective impairment in a recall of the final items of a spoken list when the list is followed by a nominally irrelevant speech item or suffix
21	Time-saving bias	Underestimations of the time that could be saved (or lost) when increasing (or decreasing) from a relatively low speed and overestimations of the time that could be saved (or lost) when increasing (or decreasing) from relatively high speed.
22	Unit bias	The tendency to want to finish a given unit of a task or an item. Strong effects on the consumption of food in particular.
23	Weber–Fechner law	Difficulty in comparing small differences in large quantities.

Appendix B

Table B.1: Ninety Design methods and descriptions

No	Method	Description
1	ABC-Analysis	ABC analysis divides an inventory into three categories—"A items" with very tight control and accurate records, "B items" with less tightly controlled and good records, and "C items" with the simplest controls possible and minimal records.
2	AD (axiomatic design)	It is a systems design methodology using matrix methods to systematically analyze the transformation of customer needs into functional requirements, design parameters, and process variables.
3	AHP(analytic hierarchy process)	Paired comparisons of both projects and criteria (all criteria are considered to be independent); compare in terms of multiple (the color is more important in double than size)
4	ANP(analytical network process)	General form of the AHP used in multi-criteria decision analysis (AHP structures a decision problem into a hierarchy with a goal, decision criteria, and alternatives, while the ANP structures it as a network.) criteria are considered to be interdependence)
5	Bayesian analysis	A statistical decision which is concerned with the problem of making the decision based on statistical knowledge (probability) about uncertain quantities
6	Bayesian Belief Network (BBN)	A statistical model used to describe the conditional dependencies between different random variables
7	Benefit analysis	Create criteria and weight in each criterion
8	Benchmark	The systematic comparison of organizational processes and performance to create new standards or to improve processes. There are 4 types of Benchmarking method: 1) Internal (benchmark within a corporation) 2)Competitive (benchmark performance or processes with competitors) 3)Functional (benchmark similar process within an industry 4) Generic (comparing operations between unrelated industries)
9	Best Practice Sharing	It is a basic idea of any benchmarking: a best practice that has been found in a competitor, by one's own employees or by organizations outside the sector, should be used in one's own company.

Appendix B

No	Method	Description
10	Black-Box	It serves to make the complexity of systems manageable. The system is regarded as a black box by initially ignoring its inner structure. By looking at the logical and statistical relationships between the input information (Input) and the output quantities (Output) one tries to draw conclusions about the opaque or invisible regulation within the black box.
11	Brainstorming	Group creativity technique by which efforts are made to find a conclusion for a specific problem by gathering a list of ideas spontaneously contributed by its members
12	Brainwriting Pool	A problem is presented to the group. Then each person writes down 4 or 5 ideas on the sheet and placed into the center of the room. Each person then picks one of the idea sheets and builds on the ideas to develop further ideas
13	BSC	Strategy mapping to visualize and communicate how value is created by the organization. A strategy map is a simple graphic that shows a logical, cause-and-effect connection between strategic objectives
14	Canonical model	Design pattern to communicate between different data formats, intended to reduce costs and standardize on agreed data definitions associated with integrating business systems
15	CBR (cased based reasoning)	Solve the new problem based on the solution of similar past problems (retrieve, reuse, revise, retain)
16	Checklist	It is a type of job aid used to reduce failure by compensating for the potential limits of human memory and attention. It helps to ensure consistency and completeness in carrying out a task. A basic example is the "to-do list".
17	Cluster analyzis	Grouping a set of objects in such a way that objects in the same group (called a cluster) are more similar (in some sense) to each other than to those in other groups (clusters).
18	Community-Plattform	Using social media (Wikipedia or Facebook...) 1) define problem 2) create idea 3) discussion 4) evaluation 5) networking
19	Concept selection (Konzeptauswahlanalyse nach Pugh) /Pugh's evaluation	Rating alternatives based on criteria and calculate the final solution by multiply criteria weight/ evaluate various alternatives against a baseline (set 0 to be a baseline and +1 is better -1 is worse) then apply weight in each criterion and multiply weight with +1,-1 or 0)
20	Conjoint Analyse	A decompositional method that estimates the structure of consumer preferences by drawing on their overall judgments about a set of alternatives (stimuli), which are

No	Method	Description
		specified by the expressions of different properties. The technique involves the analysis of choices people make and the determination of reasons behind those choices.
21	Conjunction heuristic	Based on a minimum number of criteria p that indicate positive project outcome or the maximum number of criteria n that predict negative project outcome. If the positive aspects are lower than the minimum value of the positive projects or negative aspects are higher than the maximum value of the negative projects. This project will be rejected.
22	Contact and Channel Approach (C&C2-A)	Addresses the need to associate a product's functions with is physical structure and embodiment
23	Decision node/decision map	The node where a requirement is set and that requirement determines the outcome. (conjunction of the decision tree)
24	Database system	Use a standard method to store and organize data. Data can be added, updated, deleted or transversed using various standard algorithms and queries
25	DEA (Data envelopment analysis)	Efficiency is defined as a ratio of the weighted sum of outputs to a weighted sum of inputs (find the relationship between input and output)
26	Decision score model	Decision score model: a design decision is not made at an instant in time, but based upon gradually clarification of the design and its consequences in several dimensions until satisfaction
27	Decision tree	Consist of decision point and change event
28	Delphi Method	It is a systematic, multi-level questioning procedure with feedback and is an estimation method that serves to assess future events, trends, technical developments, and the likes as well as possible. This method is based on expert interviews, and the answers are then evaluated and submitted again to the experts for evaluation.
29	Design-to-cost (DTC)	Cost management techniques describe a systematic approach to controlling the costs of product development and manufacturing (serious consideration of costs at all levels through all phases of a project
30	Dynamic problem solving (DPS)	a powerful problem-solving paradigm in which a problem is solved by breaking it down into smaller subproblems. These subproblems are then tackled one by one so that the answers to small problems are used to solve the larger ones.
31	Influence matrix/ Consistent matrix	In scenario methods (matrix that link to sub matrix)

Appendix B

No	Method	Description
32	Decision matrix	Identify criteria, weighting and compute a total score
33	Disjunctive heuristic	Accept a product if they satisfy at least one excitement rule
34	Elimination by aspect	Throwing out a bad idea by applying a subset of criteria (up to three) that is of particular importance to them. If they don't reach the minimum level in any one of them, they will be rejected
35	FAQ Kataloge (frequently asked questions)	Listed questions and answers, all supposed to be commonly asked in some context, and pertaining to a particular topic
36	FDSM (Fuzzy Design structure matrix)	Describe the dependency relationship among activities. The matrix element in FDSM have a value range of [0,1].
37	Feasibility analysis (Herstellbarkeitsbewertung)	An analysis used in measuring the ability and likelihood to complete a project successfully including all relevant factors such as economic, technological, legal and scheduling factors.
38	Fishbone diagram (Ursache-Wirkungs-Diagramm)	A visualization tool for categorizing the potential causes of a problem in order to identify its root causes.
39	FMEA (Failure Mode and Effect Analysis)	Helps define, identify, prioritize, and eliminate known and/or potential failures of the system, design, or manufacturing process before they reach the customer
40	Forecasting by analogy (Analogiebildung)	Two different kinds of phenomena share the same model of behavior. (Analogy is a cognitive process of transferring information or meaning from a particular subject) to another
41	FQFD (Fuzzy quality function deployment)	Combine fuzzy logic in QFD
42	FSEM (Fuzzy synthetic evaluation method)	Fuzzy linguistic variables are used to indicate the relative strength of the factors in the corresponding criteria, thereby constructing the fuzzy judgment matrix. The final scores of alternatives are represented in terms of fuzzy numbers. The optimum alternative is obtained by ranking the fuzzy numbers.
43	Fuzzy C-Means (FCM): Fuzzy clustering means	Fuzzy clustering is a form of clustering in which each data point can belong to more than one cluster.
44	Fuzzy Information Axiom (FIA)	For design concept evaluation: solve multi-criteria decision-making problems
45	Fuzzy logic/fuzzy set theory	It is an approach to computing based on "degrees of truth rather than the usual true or false" (0.85, not 0 or 1: probability of an interesting event is in that environment Without random)

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46	Galeriemethode	A mixture of physical and mental activity while generating ideas. The participants move past the ideas (as in the art gallery) rather than the ideas moving past the participants (group should between 5-7) -the problem statement displayed so everyone can see it. Each group member chooses a sheet and privately writes ideas onto it. participants return their own work areas and continue generating their own ideas or building on the ideas of others
47	House of quality	An important tool for QFD activities, containing information on "what", "how", the relationship between "what" and "how", and the relationship between the "how" factors themselves.
48	Hypothetical Equivalents and Inequivalents Method (HEIM)	Find preferences from the decision maker regarding a set of hypothetical alternatives in order to assess attribute importances and determine the weights directly from a decision maker’s stated preferences.
49	Kanban	Visual signal/card: signal steps in their manufacturing process. The system’s highly visual nature allowed teams to communicate more easily on what work needed to be done and when.
50	Kano method	A theory for product development and customer satisfaction, which classifies customer preferences into five categories: 1) Must-be Quality 2) One-dimensional Quality 3) Attractive Quality 4) Indifferent Quality and 5) Reverse Quality
51	Knowledge Cafe	Best convened where there are many stakeholders and opinions, and there are no right or wrong answers. A knowledge Cafe adheres to a number of conversational principles that help create a relaxed, informal environment conducive to open dialogue and to learning
52	Markov method	Used to model randomly changing systems. It is assumed that future states depend only on the current state, not on the events that occurred before it
53	MAUT (Multi-Attribute Utility Theory)	Stands for multi-attribute utility theory (or multiple attribute utility theory) it is probably one of the oldest and most established mcdm techniques.
54	Multidimensional Scaling	Arrange the objects in such a way that the distances between the objects in the room correspond as exactly as possible to the raised similarities. The farther apart the objects are, the less similar they are, and the closer they are to each other, the similar they are
55	MCDM (multi-criteria decision making)	Deals with decisions involving the choice of the best alternative from several potential candidates in a decision,

No	Method	Description
		subject to several criteria or attribute that may be concrete or vague
56	Morphologische Analyse	It is a creative heuristic method to fully grasp complex problem areas and to view all possible solutions without prejudice. This method required up to 7 people and a moderator (ideas are developed with the resulting combinations of expressions)
57	MODM (Multiple objective decision making)	Use primary for designing
58	MADM (Multiple attribute decision)	Use primarily for choosing an alternative
59	Netzplantechnik	Uses networks that describe a temporal and final concatenation of actions. It is used in particular for scheduling projects. Networks are the graphical representations of activity chains. Since activity can have several predecessors and, if necessary, successors, you get the picture of a network of activities from which the name is derived.
60	OPT (options pricing theory)	What level of research investment is justified for a particular project
61	Outside-In Technologietransfers	Cross technology from-to different groups in the industry
62	Patentportfolio	A collection of patents owned by a single entity, such as individual or cooperation. The patents may be related or unrelated
63	Pairwise comparison	Process of comparing entities in pairs to judge which of each entity is preferred, or has a greater amount of some quantitative property
64	Persona	A way to make design assumptions explicit, to create informed design choices, and to investigate design ideas.
65	Poke Yoke	A mechanism in any process that helps an equipment operator avoid mistakes. "eliminate product defects by preventing, correcting or drawing attention to human error as they occur
66	Project record	Create file and record using a keyword, category from big to small
67	Process Failure Mode and Effect Analysis (pFMEA)	It is a part of FMEA
68	Process capability analysis	Detecting the number of units that pass through each activity, or the number of units that occur as a result of the process realization. It is usually assumed that the capacities of re-sources, with which activities inside the process are performed, have to be balanced

No	Method	Description
69	Quality control chart	A graph to show how process change
70	Quality Function Deployment (QFD)	Process and set of tools used to effectively define customer requirements and convert them into detailed engineering specifications and plans to produce a product that fulfills those requirements into measurable design targets
71	Red-Tag-Analyse	Separate useless from useful things and is often used to create order in the workplace. This requires an appointment from all participants. It crystallizes out, with which articles it is worthwhile to hold them always in stock and with which articles it is more meaningful to order them depending on the need
72	Reviewing reference projects when designing new project	Analyze and create an idea from the previous project. It helps you to know how the solution comes, how to make it better
73	Scenario analysis	Solving the problem for different scenarios and studying the solution obtained
74	Scenario management	It is a method to manage the complex planning situation and is based on scenarios that are adjusted precisely to their enterprise
75	Sensitivity method	The optimal solution and the optimal objective value are affected by the changes of the uncertainty parameters (base on the scenario)
76	SMART (Simple multi-attribute rating technique	A given alternative is calculated as the total sum of the performance score (value) of each criterion (attribute) multiplied with the weight of that criterion
77	Stimulus word analysis	The moderator presents the problems to the participants and explains the stimulus word analysis. Stimulus words are chosen and within 15 minutes the participants search for a solution to the problem
78	Synectics	A creativity method of identifying and solving problems that depend on creative thinking, the use of analogy, and informal conversation among a small group of individuals with diverse experience and expertise. (1 understand the problem 2 idea generation from personal idea 3 idea generation from analyzing the direct factor that causes problem 4 idea generation from analyzing relevant factors that cause the problem 5 select solutions)
79	SWOT-Analyse	Used to evaluate a company's competitive position by defying it "strength", "weaknesses", "opportunities", and "threats"

Appendix B

No	Method	Description
80	Tallying	Give the score (+1 or -1) to alternative related to criteria without ordering the important and summarize the score from all criteria (>0 accept, <0 reject)(check positive>negative)
81	Take the best	Order the most important criterion and evaluate the alternative to pass or not pass that criterion; if pass check another criterion if not then reject
82	Technical feasibility study	Uncover the strengths and weaknesses of an existing business. The goal is to determine the project whether the project should go ahead, be redesigned, or else abandoned
83	Technology Roadmapping	Flexible planning technique to support strategic and long-range planning, by matching short-term and long-term goals with specific technology solutions. Phase1: preliminary phase (satisfy essential conditions, provide leadership/sponsorship, define scope and boundaries for the technology roadmap) Phase 2 development phase Phase 3: follow-up activity phase
84	TOPSIS (a technique for order preference by similarity to the Ideal Solution)	Select the alternative that is the closest to the ideal solution (one which has the best attributes value) and farthest from negative ideal solution (one which has the worst attribute): implement method after decision matrix. Concentrate on the different of the highest and lowest score
85	Trend analysis	It is assumed that prices tend to follow patterns as they have in the past due to similar reactions of investors. There are 2 types of chart patterns: 1)Reversal patterns: signal potential reversals during existing up and downtrends 2) Continuation patterns: signal potential continuation of the existing up or down (data are collected and evaluated to identify patterns of information that might impact future)
86	TRIZ	A problem-solving, analysis and forecasting tool derived from the study of patterns of invention in the global patent literature. TRIZ is an algorithmic approach to finding inventive solutions by identifying and resolving contradictions.