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An Investigation of Fast and Frugal Heuristics for New Product Project Selection

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An Investigation of Fast and Frugal Heuristics for New Product Project Selection

by

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ABSTRACT

In the early stages of new product development, project selection is dominantly based on managerial intuition, rather than on analytic approaches. As much as 90% of all product ideas are rejected before they are formally assessed. However, to date, little is known about the product screening heuristics and screening criteria managers use: it has been suggested that their decision process resembles the “fast and frugal” heuristics identified in recent psychological research, but no empirical research exists. A major part of the product innovation pipeline is thus poorly understood.

This research contributes to closing this gap. It uses cognitive task analysis for an in-depth analysis of the new product screening heuristics of twelve experienced decision makers in 66 decision cases. Based on the emerging data, an integrated model of their project screening heuristics is created. Results show that experts adapt their heuristics to the decision at hand. In doing so, they use a much smaller set of decision criteria than discussed in the product development literature. They also combine heuristics into decision approaches that are simple, but more complex than “fast and frugal” strategies. By opening the black box of project screening this research enables improved project selection practices.

DEDICATION

To my Parents for their endless, love support and encouragement

To my children for all the moments I took away from them to fulfill my dream

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This is only the beginning of my journey.

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CHAPTER 1: PROBLEM, OBJECTIVES AND OVERVIEW

1.1 Screening Methods in the Fuzzy Front End

The early stages of new product development are frequently referred to as the fuzzy front end (FFE) [1] because they are poorly structured and documented. Front end activities are focused on information gathering, idea and concept development, planning, and evaluation [2]. They culminate in the decision to abandon a product idea or to accept it and to define a formal product development project and approve its budget, timeline, and work description [2]. The screening of innovation project proposals in the front end is considered one of the most challenging tasks for senior management [3]. Screening decisions are complex and made under high levels of uncertainty based on relatively limited information. At the same time, they affect a firm's future in terms of profitability and survival and have consequences for the allocation of resources and the development of key competencies [4, 5]

Front end screening is highly selective. There are always more ideas than can be thoroughly evaluated, let al. one funded [6]. It heavily relies on managerial judgment or heuristics: Griffin [7] shows that approximately 50% of all product ideas in the front end are abandoned even before analytical project selection methods, such as a business analysis, are being employed and that less than 40% of the initial ideas make it into product development. Stevens et al. [8] state that the ideas that make it into the organizational idea pool ,and are briefly- considered in the front end, are only the tip of the iceberg. According to Stevens et al. [8] estimates 90% of 'raw' ideas do not find a sponsor who is willing to take at least minimal action, such as performing simple experiments or discussing the idea with management. Managerial heuristics furthermore play an important role in the so called initial reaction a quick, early screen of ideas that relies on the experience of managers who act as gatekeepers and determine which ideas should be considered in the front end evaluation system [9].

However, to date, little is known about how managers make early stage screening decisions. There is anecdotal evidence that screening decision are based on very simple and highly individual approaches that are sometimes verbalized as simple rules, such as "look for companies selling aspirins, rather than vitamins," or "find markets the size of Texas" [10] page 282 - on venture capital screening. Screening decisions are furthermore based on few criteria. One venture capital broker reports that he screens investment proposals based on only three questions: "Is it a big market? Can your product win over and defend a large share of that market? Can your team do the job" [10] p.228. Accordingly, Exxon Chemicals moves projects to the next decision gate if a team of screeners agrees (without extensive research) that it fits strategically, addresses an attractive market, is technically feasible, and does not suffer from any killer variables such as regulatory restrictions [6]. Research on gatekeeper behavior in the front end product development furthermore demonstrates that gatekeepers rely on experience to assess a small set of criteria before they take up new ideas, provide resources (such as access to networks of decision makers) and promote the idea so that it can be evaluated in the company's front end funnel [11, 12]. They are likely to accept a raw idea and promote it quickly if they recognize its value and feel that the costs and risks associated with the project are acceptable [12]. This gatekeeper behavior can result in an ‘initiation gap’ for technology-driven, radical innovations, which fail to be evaluated, and consequently funded, because they are uncertain and do not easily fit the evaluation criteria and management approaches that management usually employs [13].

Current research thus provides evidence that early stage project screening occurs through simple heuristics that focus on a few criteria that are evaluated with equal weights and in a non-compensatory fashion. However, the actual screening heuristics used are unknown.

This dissertation opens the black box of managerial screening heuristics by investigating the screening behaviors of experienced gatekeepers through cognitive task analysis.

1.2 Research Objectives

The intent of this study is to advance existing knowledge toward a more complete understanding of expert judgment behavior related to screening projects at the FFE of NPD by investigating the decision heuristics that are currently used by managers for screening new product proposals at the fuzzy front end and to model them. Such a detailed description of heuristics will allow researchers to evaluate the quality, accuracy, and overall effectiveness of these heuristics, and create heuristics-based, simple decision models that fulfill management needs during the fuzzy front end of new product development.

The objective of this research is summarized into two main goals:

G1. Discover decision makers' heuristics for FFE project screening

G2: Structure the observed heuristics in systematic models

This research is concerned with answering four research questions:

RQ1: What are the main objectives and constrains for FFE project screening? (Context of heuristics)

RQ2: What are the criteria used in the evaluation process? How are they ranked or weighted? How are they used to discern alternatives? (Structure of the heuristics)

RQ3. Are similar heuristics used by different managers? (Patterns of use)

RQ4. How can the identified heuristics be modeled? (Model heuristics)

1.3 **Research Approach**

Three major activities were undertaken: 1) extensive review of the literature on decision approaches and an evaluation of their applicability for project screening at the FFE, then review the literature on the theory and practice of heuristic, emphasizing on the "fast and frugal" decision making heuristics, 2) field study to elicit the heuristic decision processes used by expert project screeners, 3) modeling of the heuristic processes identified in the field study.

The findings of the desk study will be covered in Chapter 2. Chapters 2.1 and 2.2 identify the features and requirements of project screening in the FFE, describe commonly used decision making tools for project selection, and assess their applicability for FFE screening. Chapter 2.3 introduces managerial heuristics as an alternative decision making approach and describes their theoretical bases.

Chapter 3 identifies the gaps in current state of art in regard to FFE screening which this research is aiming to close, to answer four research questions.

Chapter 4 introduces the research methodology for the field study by studying the theories and practices of knowledge engineering, which, as a field, captures expert knowledge for the design of knowledge-based systems [14]. Cognitive Task Analysis provides an important methodological framework and with a variety of approaches for expert identification, knowledge elicitation and capture, knowledge modeling and for ensuring reliability and validity of the research findings [15, 16].

Chapter 5 is devoted to data collection and analysis. A total of twelve respondents were researched, leading to about 66 project screening decision cases. Data analysis was done in multiple phases of process analysis technique using QSR NVivo 9. The results of the data analysis process are discussed in Chapter 6 along with the steps taken to ensure the validity of the research results.

The seventh and final chapter, Conclusions, reviews the findings of the study, discusses its contributions and limitations, and recommends directions for future research.

CHAPTER 2: LITERATURE REVIEW

The purpose of this chapter is to provide a comprehensive study of judgment behavior in the context of project screening in the fuzzy front end (FFE) of new product development (NPD). It reviews three major research streams:

The first part (section 2.1) studies the literature on new product development, emphasizing on understanding the context, importance, characteristics and needs of early project screening at the FFE stages.

The second part (section 2.2) reviews decision management methodologies and tools to support FFE project screening that were previously proposed in the literature, namely analogy-based models, economic models, multi-criteria decision models, decision trees, and heuristics decision models. Based on the review, screening heuristics are identified as a potentially useful approach to front end screening.

The third part, (section 2.3), discusses the theoretical foundations of research on heuristics and presents the limited empirical findings on the subject that is currently available. Section 2.4 summarizes the gaps identified in the review of the state-of the art.

2.1 New Product Development and the Fuzzy Front End

The NPD process is highly selective; by some estimates, it takes as many as 3000 raw ideas to get 300 ideas in the front end idea pool [8]. Approximately 50% of ideas that make it into the idea pool, are abandoned before any analytical project selection methods are used, 10% make it to the business concept stage, only 4% get to the business development and just 1% of the projects succeed in the market [7] (See Figure 2.1).

This makes R&D project selection a crucial task for any firm seeking new product success [17]. Project selection is a complicated decision making process that features multiple stages, multiple groups of decision makers, and often conflicting objectives, in addition to high risk and high levels of uncertainty in predicting future success and product impact on the market [18].

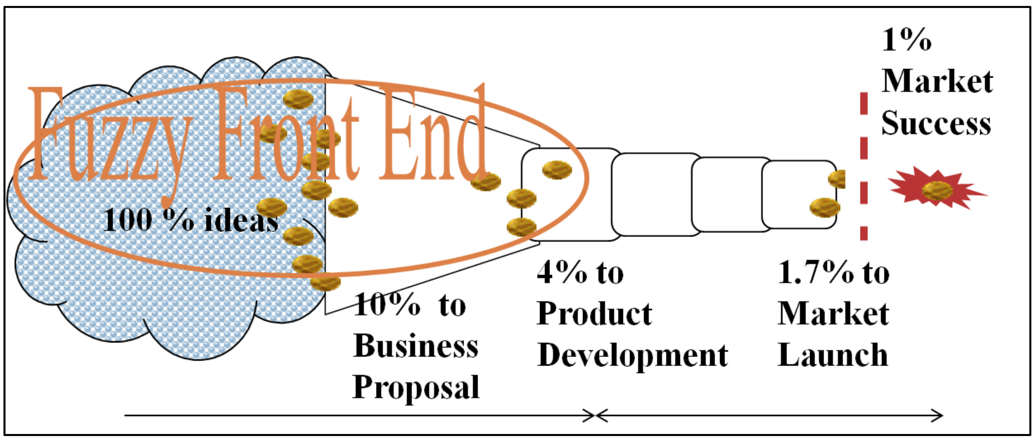


Figure 2.1 New Product Development Funnel

The NPD portion may be divided into three processes: first, the fuzzy front end (FFE), where ideas are screened, evaluated and turned into concepts; second, the product development stages, where all product developing planning; and third, designing and commercialization and marketing stages take place [19].

A new product idea goes through different stages to eventually turn into a complete product; these stages ne zed special screening techniques to approve the product to the next stage [20]. In addition, these screening techniques need to fit the purpose and characteristics of each stage.

This first part of the literature review (2.1.1) examines the different NPD frameworks in which there are three different approaches that take the new idea until it turns into a final product. Then 2.1.2 narrows the focus to the very early stages of product development—the fuzzy front end, where it discusses the features of and the characteristics of this stage (2.1.2.1), summarizes the requirement of the screening methods needed at this FFE gate (2.1.2.2) and finally (2.1.2.3) emphasizes on the practices of FFE screening.

2.1.1 **New Product Development Frameworks**

NPD framework can be represented as a system whose elements are partially connected and have the capacity for autonomous decision making and social action [21]. From an idea to commercialization of a new product, there are many steps, processes and evaluation points. Evaluations occurring at any point greatly influence what will happen in the next stage. The principal role of NPD decision makers is to make judgments and choices to bridge the gap between the innovation idea and reality [21] and choose projects with potential success [21]. At screening gates one of three decision options need to be made: 1) commit resources needed and proceed forward with the product developing, 2) put the product development on hold waiting for future decision trigger, 3) drop the product completely from the development portfolio [20, 22].

Given the importance and value of NPD, researchers have developed descriptive frameworks of the NPD process that reflect three different system views: the linear framework, the recursive framework, and the chaotic framework. Although these three frameworks provide different insights and descriptive theories about the NPD process structure and behavior, as summarized below, all of them describe selecting innovation idea in to the project pool as an area of uncertainty and fuzziness.

Linear Frameworks

Linear NPD frameworks represent the traditional and logical project management model, which divides the process of NPD into a series of events and activities, which are sequential and discrete in nature. The most well-known linear framework is the stage-gate evaluation approach (sometimes called 'game plans' or 'stage-gate systems') [9, 20, 23, 24]. This common framework divides NPD into stages that are separated by decision gates, which start with idea generation and then go through many other stages such as concept development, product design, product development, market testing, and culminate in a complete product ready to be launched. These stages are represented in (Figure 2.2) [20, 25, 26].

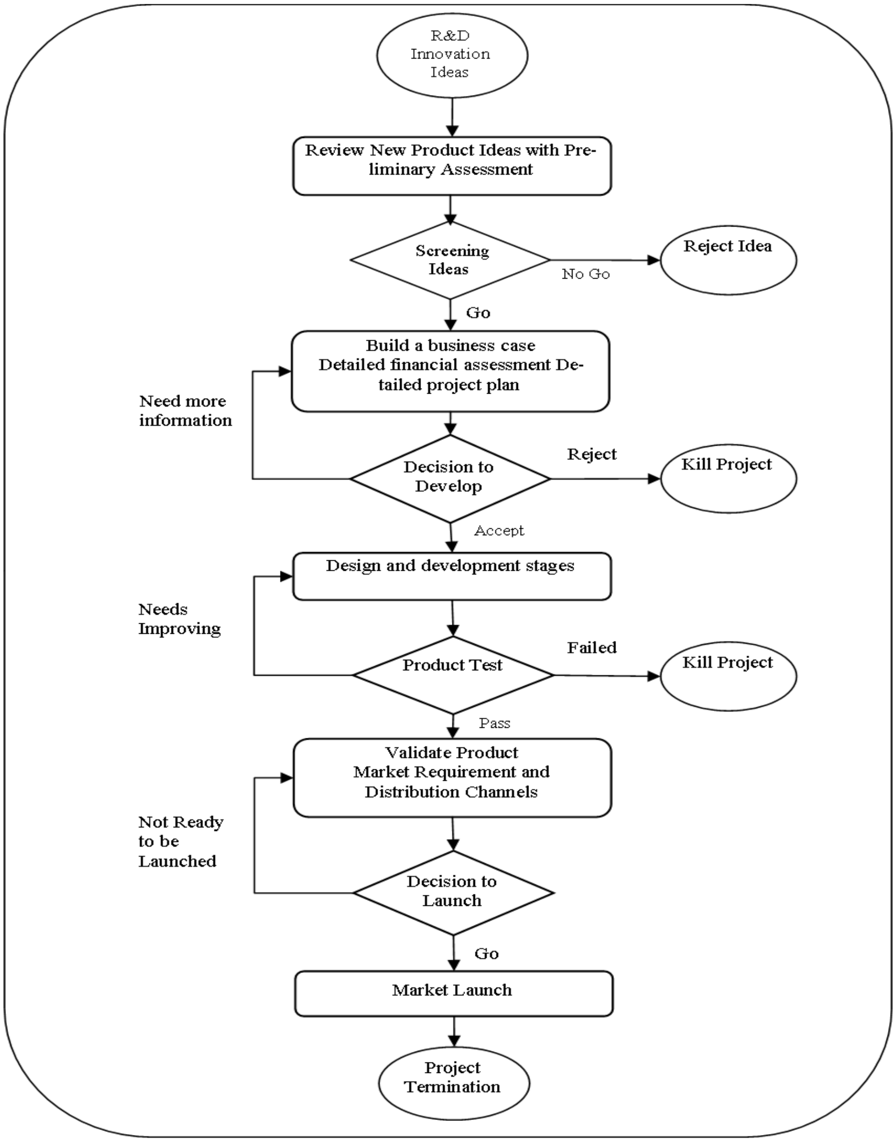


Figure 2.2 Linear Framework of NPD Evaluation System

Each stage is followed by a gate where evaluation takes place and a decision has to be made about whether to continue processing the project and move into the next stage or to kill it. Each gate consists of different combinations of technical and commercial evaluation sets that act as quality control check points for product development [20, 25].

At the first gate, product opportunities and product ideas are screened to identify those ideas that are promising and should be developed further into product concepts. On average, only 10 out of 100 projects make it through this gate [27]. Filters at this gate should typically be designed to be fast, cheap, and not very permeable to give quick evaluations for projects in order to identify those projects that should be transferred to enter the full screening gate, and those project concepts that should simply be killed. Since there is little known about the project at this stage, decisions depend on a limited amount of information [20]. After a project passes the early screening gate, a detailed assessment is conducted by building a business case, setting the project plan, and studying the market in further detail including the competitive analysis, detailed technical appraisals and manufacturing assessment financial analysis [20]. As the development project proceeds, more information is collected about both technical and commercial feasibility. Because the information at these later stages is related to something tangible, the information has greater potential for being reliable and valid, and a decision can be made depending on this reliable information. When a project reaches the testing stages, the information will become more complete and encompass customer opinions, buying behavior, operation of the product in use, production and delivery, and the target market [25].

This stage-gate concept seeks to deliver appropriate outputs on time and within cost by applying process management techniques to enhance the effectiveness of the process, ease the task of setting goals toward completing each phase, improve focus on a particular phase, and reduce risk [21, 23]. Empirical research has found that stage-gate processes reduce development time, produce marketable products, and optimize internal resources by eliminating projects which are not promising or likely successes [23]. However, the focus on process structure, reliability, and control has tended to ignore human behavior aspects and system features that fundamentally influence and affect the NPD process [21]. This happens because linear frameworks represent the NPD process as a mechanism that evaluates the activities in order, while ignoring other process factors such as flexibility, informality, feedback, and autonomy. This makes linear frame work more suitable for incremental innovation than for radical innovations [28].

Since new product development is increasingly managed with flexible decision points, researches proposed the recursive and chaotic NPD frameworks [29, 30], to give advanced interpretation and understanding of the activities that underlie the development of radical innovations [31-33].

Recursive Framework

Critics of linear process models state that these models misrepresent the nature and direction of the innovation because innovation is a complex, uncertain, disorderly process during which the original idea usually changes many times through different stages [32]. Furthermore, Leonard-Barton [34] states that implementation is part of the innovation and the implementation of new technology cannot be separated from its creation. Therefore, a recursive framework has been proposed as one of the alternatives to the linear framework. A recursive framework is built on the fact that the most important innovations go through essential changes during their life cycles and that these changes often transform the initial inventions into different products [32].

A recursive framework represents NPD as multiple, concurrent and divergent activities that include chain-linked models recursive cycles feedback and feed-forward loops that describe the relationships and iterations among research, invention, innovation, and production [21, 32, 34, 35]. The decision of selecting an innovation idea to the production is affecting the rest of the chain. However, recursive models do not provide a structural format for the process, which make it hard to follow, and to systemize [32, 33].

Chaotic Framework

The chaotic framework is an extension of the recursive framework that represents innovative NPD processes as a system with "nonlinear behavior that generate irregular or, disordered series of actions" [21] page 440 , where this system starts chaotically and finishes in more stable, systematic stages that are similar to the linear stages [33]. This view relies on research that suggests that front end activities (such as search, screening, and implementation) cannot be addressed separately from each other, and shows that the feedback loops as influential properties of these activities [36]. A chaotic framework is less structured than the other two frameworks and is hard to follow or adapt. Therefore, making a decision to take an idea from innovation to the product production tunnel does not have clear structure or follow any systematic model.

The summary of these three models is presented in Table 2.1.

Table 2.1 Linear, Recursive, and Chaotic Frameworks of New Product Development [21]

Linear	**Recursive**	**Chaotic**
It is a simple and effective representation of relatively fixed, and discrete process for NPD, Project goes through sequential stages followed by evaluated gates. It does not consider the dynamic behaviors and relationships each stage and gate have once chance once the project pass it cannot go back. It represents a good fit for incremental innovation activities with relatively reliable market.	A process is represented in a concurrent and multiple feedback loops between stages. These loops represent the dynamic and the nature of the process. However, it does not represent the structure or the behavioral format of the process. This model matched the need of radical innovations activities, technology transfer and competitive markets	Representing different degrees of feedback across the process Where the initial stages are chaotic and dynamic, latter stages are relatively stable and certain. Recognizes different system behavior across process but does not consider the adaptability. It suits the needs of radical innovation research or new to the world products.

Individually, each framework provides valuable insights about the behavior and structure of NPD processes. However, collectively, they are more than just rival frameworks. As a group, they provide rich and holistic interpretations of the NPD processes and facilitate a contingency theory approach [21]. The linear model assumes that an idea is only screened once at each gate and moves downstream or is abandoned – without going back. A recursive framework allows multiple screenings at the same level to allow for learning; so screeners need to look for early screening tools that are easy to update. A chaotic framework may allow projects to progress without any clear screening at least in the early stages. Still, in these three models, the FFE suffers from "fuzziness" and uncertainty, and decision makers need quick and cheap screening tools to decide either to move forward or to eliminate the idea. Therefore, we study this early screening phase further more in the next section.

2.1.2 **Fuzzy Front End**

The real keys to NPD success can be found in the activities prior to the actual project development [20, 22, 37-40]. The very early stage of product development, known as the fuzzy front end (FFE), encompasses a variety of planning activities that precedes the concept, where the opportunity and risk are identified and assessed. The term FFF became frequently in use in the early '90s [1, 29]. The interest in the FFE as an important stage in the product development life cycle has recently increased [3, 5, 12, 41, 42]. Pre-development activities are critical factors for project success, and play a great role before any resources or funds are allocated to projects [22, 23, 25, 43]. FFE is generally considered as one of the largest opportunities to improve and speed up the NPD process [1, 29]. Projects had a better success rate when managers spent more time and effort studying the new product and not skipping ahead to the project development stages [20, 40]. Cooper [20] found that when pre-development activities applied carefully, projects had about 75 percent success rate and 45.7 percent market share, while those projects lacking pre-development activities failed 70 percent of the time. Researchers have made efforts to evaluate the impact of the front end on NPD performance [2, 20, 22, 25, 37, 39, 40, 44, 45] and to examine the different processes used in the front end itself [19, 27, 29, 46, 47].

Research [2, 48, 49] considers the fuzzy front end as a series of actions that include idea generation, opportunity identification and assessment, product definition, project planning and executive reviews, product strategy formulation and communication. FFE decisions have three potential outcomes: identifying the project idea as a good idea that deserves further study and proceeding forward, procrastinating the project for future decision trigger, drop the project from the NPD pool [9].

In the screening stage, it is important to eliminate the project early if it has been tagged as likely to fail. Managerial problems arise in making two types of wrong decisions: rejecting successful projects (which has been known as a type A mistake) and continuing with a losing project (which been known as a type B mistake) [9, 29]. In the first case, when a company discards a winning project idea, it does not lose money from not developing the project, but the company does lose ultimate profit [9]. In the second case, even if the bad project is discovered in later stages, terminating a project after allocating resources to it is a difficult decision. If a project fails in later stages, the costs are likely unrecoverable [50]. In addition, choosing a weak project in early screening prevents good ideas from being developed with regard to limited resources and funds firms can offer for developing new ideas [50]. Some studies consider rejecting good ideas as a worse error than accepting losing projects because the profit that can be gained from a successful idea is greater than all the development costs combined [9]. Other studies

[29] consider accepting losing projects as the critical error that needs to be avoided. Table 2.2 shows these two types of errors in project selection.

Table 2.2 Types of Decision Error at the FFE

Incoming Project Concept	**Decision can be made**	
	Reject the project	**Accept and move to next**
Bad Idea	Correct decision	Incorrect decision (Go error)
Good Idea	Incorrect decision (Drop error) (Type A)	Correct decision

The FFE screening, however, does not only have to be effective, but also has to be done quickly and efficiently to keep the cost of screening acceptable. From an economic perspective, delaying making decisions at the FFE, until collecting more information or having market researches, may become more expensive than making a wrong decision at the early stage because the decision will be revisited in later stages. Reinertsen in their illustration [1, 29], estimated the average computed cost of delay for projects to reach $100,000 per month, with a six month average cycle time. On average, delay announcements of new product decrease the market value of the firm by 5.25% [51]. Thus, there are significant penalties for not introducing new products on time.

2.1.2.1. Fuzzy Front End Features and Characteristics

While the later stages deal with fewer numbers of projects, the early screening stage deals with tens, sometimes hundreds of R&D project concepts proposed for screening, which makes the number of screening decisions that need to be made, very large [52]. Since the initial screening is more concerned with identifying ideas that can be developed into concepts and can be evaluated for their technical feasibility and market potential, rather than providing detailed analysis, screening should not be very sophisticated and accurate and furthermore limited by the large number of projects that need to be screened, the limited time available, and a lack of information [25, 29].

The main challenge in making decisions during the project screening stage is uncertainty. Information available at this stage is incomplete, which makes estimating project success difficult [2, 9, 11, 27, 29, 39]. As projects move through the development stages, the amount of data increases dramatically and the quality of available information improves [9]. More and more information is available at the commercialization stages, but by then, it is too late to cancel a project [22, 50] without incurring high losses.

The FFE stage has characteristics that make screening projects at this stage different than other later stages. These characteristics of FFE make decisions at the early stages of product development critical, and require screening approaches that can work with limited data and time, and effectively link business strategy and product strategy to product-specific decisions [9, 38, 46]. They are summarized in Table 2.3, which compares FFE screening characteristics with the characteristics of full screening and later screening. Full screening results in the decision to develop a product or not, whereas late screening takes place towards the end of product development to decide if a product is ready for the customer of not [9]. We compare these three stages in terms of number of project evaluated, data availability and reliability, and the time available to make such decision. This evaluation takes place at a scale level from high (H) to Low (L).

Table 2.3 Levels of Evaluation Variables in Different Stages of Product Development

Stage of Product Evaluation	Evaluation Variables											
	Number of Project to Evaluate			Data Availability			Data Reliability			Time Availability		
	H		L	H		L	H		L	H		L
FFE Screening	X					X			X			X
Full Screening		X			X			X			X	
Late Screening			X	X			X	X			X	X

2.1.2.2. Requirements of FFE Screening Methods

FFE Screening is an essential step to save limited resources for worthwhile projects. The goal of early screening is to determine the "big loser projects," to drop them out of the NPD pool, and spot the potential winners to proceed forward to be able to hit the competitive market while the opportunity window is still open [9]. The layout of the screening 'filters' should take the cost of filtering, the cost of time delaying and the cost of errors into account [30]. Since the project goes through many stages, where there are many check points, the 'Go' decision, made at the early gates, is not an irreversible decision. Early stages' decisions do not commit all needed resources for the entire project; it just moves the project forward for the next stage. NPD team has the flexibility to kill the project in the subsequent stages, especially before implementation begins, if indications of project failure are found [11, 38]. Since wrong decisions are still reversible, information is scarce, and managers do not have time to study all proposed ideas in detail, a 'good enough' evaluation of project concepts is accepted at this stage. FFE screening criteria are different than criteria used for other screening gates, because of the nature of the FFE. For the limited information available at the FFE screening, criteria may not always be quantitative or comparable and/or they might differ from one project to another depending on the goal and the nature of each project; and so, these criteria should carefully be selected and weighted to the best use of the FFE screening [25]. New product development is dealing with R&D innovations ideas; some of these innovations are new to the world, which require flexible and visionary evolution to assess the quality of these ideas.

As a result, FFE screening method should be designed to be flexible enough to consider new ideas and multiple objectives, to allow criteria changes, to provide a good enough evaluation of project concepts fast and cheap, and to be easy to implement and use criteria [1, 20, 29, 38, 53].

The unique characteristics of FFE screening (Table 2.4) will be used later to develop criteria to be used in evaluating the current screening practices and screening methods proposed in the literature in the subsequent Chapter (2.2).

Table 2.4 FFE Characteristics

Limited accurate information
Limited time and resources
Evaluating criteria might change, depending on the project and changing environment
Incremental and radical innovation projects need to be evaluated not in comparison with previous projects
Project proposals are typically screened one-by-one (not as a group)
Seeking 'good enough' if not 'optimal' results from a reliable method.
Fuzziness and uncertainty.

2.1.2.3. FFE Project Screening Practice

A review of project screening and evaluation practices shows that managers tend to use project management decision models near the end of the development process, where there is more information available, and market uncertainties become more important than technical uncertainties [9, 25, 52]. Relatively little time or money is spent on the up front activities [20, 38-40]. On average, only seven percent of the project's total expenditures and only sixteen percent of the person-days are devoted to these critical predevelopment activities [39].

Cooper [22], after studying 252 new product cases from 123 companies and interviewing the new product managers, found that initial screening was undertaken in over 90 percent of the projects. However, it is rated as the weakest evaluation activity, scoring lowest on the proficiency scale, and noted as an activity that needs great improvement. While decisions are supposed to be made on the basis of rational analysis of potential profitability, in 60 percent of the cases examined by Cooper [37], screening decisions were made by a single individual or an informal group, based on informal decision techniques.

Another study by Hart [25] that surveys of 166 managers from companies that develop and manufacture industrial products in the Netherlands and the United Kingdom, found that about 58 percent of the managers use intuition as one of the most important evaluation techniques in the concept screening stage. Research [20, 22, 37, 40] show that gut feeling, past experiences, faith in certain individuals, hopeful guesses, and wishful thinking seem to be the decision factors in most cases. Ideas are rejected intuitively as a result of informal peer discussion or one or more levels of supervisory review [52], and if decision aids are used at all, they are very simple. Checklists are used in group decisions in about 11.6 percent of the cases, while in less than 2 percent of the cases, evaluators used a formal checklist questionnaire or scoring model to rate projects [38]. These facts indicate that few managers are taking advantage of the available management science tools, most likely because these tools fail to reach their full potential in the FFE screening [54]. Research [22, 26, 38, 40] show that this is due to a lack of simple systematic managerial approaches that fit with the nature of new products that require innovation [55]. Because these techniques are unable to consider strategic factors or to use the imperfect and incomplete information available at this early stage of NPD, they tend to be complex and time consuming [17, 56, 57].

2.1.3 **Summary and Discussion- Part 1-New Product Development**

The discussion above has shown that all frameworks for NPD characterize the FFE as a distinct phase of the development process that is different from later development stages because of the large number of ideas need to be screened, because information and time are limited, and because screening criteria need to be adapted to changing projects.

Presently, front end decisions are often based on non-analytical factors, poorly documented and stretch over a long period of time, rather than resulting in a clear decision to pursue a project or reject it [27, 29, 39, 47]. Consequently, many practitioners express dissatisfaction with the front end process [20], which is presently not fast and not successful enough. As a result, new approaches to decision making are urgently required [2, 47].

Management science has provided solutions for NPD screening at the downstream end of the development process where data is available to feed elaborate models. However, it did not offer much for the front end, where simplicity is virtue, and the gathering of information and use of complex models could result in long time delays and high costs. In these early stages, the use of simple and possibly less reliable screening methods is acceptable, because decision errors are cheap, since they will soon be caught at a subsequent checkpoint. It is therefore acceptable to sacrifice decision quality and choose a simpler, faster, and less expensive evaluation method. Decision aids for FFE screening must be able to address the needs of the FFE process [25, 38, 50, 52]. The next section reviews different decision making methods that have been proposed for project selection, in terms of their applicability for screening projects at the FFE.

2.2 An Evaluation of Decision Models for Project Screening

With regard to the characteristics identified previously and summarized in Table 2.4, there are only few publications that evaluate the managerial decision tools with regard to their usefulness under different situations [54, 57]. "Most research in the area of opportunity identification has presented the procedures and theoretical foundation of a single method, and little has been done to assess methods in terms of their appropriateness" [54] page 182. Even fewer publications comment on the value of screening methods for the early stages of new product development.

This section aims to close this gap in Management Science literature, by assessing the most well-known decision models for project screening based six criteria developed based on the FFE characteristics identified previously. These criteria are summarized in Table 2.5. These criteria are used to assess the appropriateness of decision methods to eliminate the losing projects and identify the potential winners at the FFE.

Five classes of decision tools will be covered in this study: analogy-based models, which screen projects by comparing them to historically successful projects, economic decision models, which exclusively rely on financial data to evaluate projects, multi criteria decision models, which consider a variety of different criteria, decision trees that illustrate the probabilities of alternative outcomes, and finally the heuristic decision models which are simple rules of thumbs that individuals and groups use to reach a decision.

Table 2.5 Criteria Used to Evaluate FFE Screening Methods

Evaluation criteria	**Description**
Information	Ability to perform using limited accurate data
Time	Fast and cheap to be used to evaluate many projects
Flexibility in Changing Criteria	Flexibility to use different criteria
Independent Evaluation	Ability to assess projects independently, not comparatively with other proposed projects or historical data
Evaluate Single project	Can be used to evaluate single project not group of projects
Operational usefulness	Freedom from ambiguity regarding interpretation of inputs required from the decision maker Overall quality of performance is good enough if not optimal
Codification	Transparency of the logic of the decision method

Conceptually, these models, except heuristics, were built based on the classical decision theory, which represents the decision situation as a decision matrix that consists of information, alternatives, and outcomes.

They determine the outcomes by evaluating the value of each alternative under the decision situation [58, 59]. However, these models vary with respect to their objectives, performance, applicability to different projects, data requirements, suitable environment, time frames, and diagnostics [60]. Table 2.6 shows these models with their respective application areas.

Table 2.6 Category of Decision Making Models

Method	Key approach	Application area	References
Analogies	Comparison of current projects to historical data of similar products and search for an optimal solution/alternative with regard to some objective functions	Project idea has suitable analogy with previous projects or has been formulated in a mathematical programming model	[9, 38, 61-68]
Multi-Criteria	Assessing alternatives with regard to multiple criteria and based on preference of decision makers	Project idea and its attribute are clearly defined and decision makers' preferences are known	[18, 50, 57-59, 69-79]
Economic Models	Forecasting of financial outcomes	Project idea has well known market opportunity and cost structure	[9, 25, 80-87]
Decision Tree	Assessing alternatives under different scenarios, for which the probability is known, based on a single criterion (typically	Project idea, alternative scenarios, and their probability are well-known	[26, 52, 83]

	payoff)		
Heuristics	Using general knowledge "rules of thumbs" to solve problems	Project ideas with limited available information; decisions under time pressure	[63, 85, 88-113]

2.2.1 **Analogies**

Analogy-based models are comparative models that use historical data to create statistical models that compare the current projects with data from previous projects to compute the probability of project success and the overall value of the project [83]. This method helps to predict project performance and helps companies to determine the market effort required to achieve similar results when the nature of the projects and the environment are similar [60].

The New Prod Model, proposed by Cooper [38], is an example of a well-known analogy-based decision model that contains a large amount of data organized in a database system and used to assist mangers in making NPD screening decisions while depending on comparisons with the historical data saved in a database.

Analogy-based models that use multiple regression models are popular methods for forecasting when data on relevant independent variables (or attributes) is available. Although many researchers [50, 55, 60] support the opinion that analogies models lay down a good foundation for NPD decision methodology [55], they considered several limitations for such methods. It was found that these models perform relatively poor as forecasting tool when there is no enough information available, compared with the performance of other forecasting models given similar amounts of available information. Even forecasts based on human judgment outperformed multiple regressions in some cases [64, 92, 114].

Since the evaluation of analogies models is based on comparisons with past project experience of some companies from different industries, these historical experiences were sometimes found to not be applicable to the current projects because of rapid changes in markets and technologies or because of the difference between companies' practices and backgrounds. A key finding from Hassard et al.'s study [115] is that new product developers rely on an initial analogy even in the face of overwhelming evidence of the inappropriateness of that particular analogy; suitable analogies may not exist for 'new to the world' products, and, in general, it requires many details about the new project which may not be available at the FFE stage.

The decision criteria used in the evaluation are usually fixed, and based on judgments made by multidisciplinary teams that constitute members from different departments and different industries which may differ from the industry at hand [50]. Analogy-based models (especially the new software built to perform all calculations) are easy to use and comprehend, but they do not provide a logical mechanism to produce group judgments in the evaluation of projects [55, 74].

2.2.2 **Multi Criteria Decision Models**

Multiple Criteria Decision Models (MCDM) have been defined as "a formal approach to types of problem solving (or mess reduction), lies in attempting to represent such imprecise goals in terms of a number of individual (relatively precise, but generally conflicting) criteria" [57] page 569. Using MCDM requires decision makers to state clear objectives and goals, review the different alternatives using the consistent set of chosen criteria, then determine the outcomes using a utility measure [38, 59]. They are widely used approaches for project selection, because they can be flexibly adapted to decision makers objectives and preferences and because they help to keep the judgment objectives clear [38, 55]. Three of the popular MCDM (scoring models, AHP, and the fuzzy based decision models), will be studied the next regard to their relative applicability for project screening at the FFE.

2.2.2.1. Scoring Model

Scoring models are multi criteria decision models that evaluate projects under different criteria, and use mathematical formulas or algebraic expressions to calculate the outcomes [72, 83]. Scoring models can take the shape of an arrangement checklist criteria with weights of importance assigned to each criterion. After evaluating the project concepts using these criteria, all weights are mathematically combined to come up with project score. Project scores are compared against other alternative projects or against historical data to help make decisions and select a certain project [9, 72].

It takes time to develop a scoring evaluation system, but once it is designed, it does not require much effort to run it. Scoring models are usually used for group evaluation where each team member assigned weight for the project under each criterion depending on their personal judgment with regard to the available data. There are various mathematical methods to combine the individual team members' ratings, which needs a certain level of knowledge and experience [9].

2.2.2.2. Analytic Hierarchy Process

Analytic Hierarchy Process (AHP), which was developed in 1980 by Thomas Saaty, systematically compiles groups of expert judgments to choose an alternative among different choices in a certain issue [57, 79]. It is a powerful decision technique to tackle complex problems of choice and prioritization [9, 50, 83]. AHP builds a hierarchal structure for the problem and effectively integrates the evaluation of the entire hierarchical model [18, 75]. After identifying the company's objective, different levels of judgment criteria should be identified and prioritized against each other on a pair-wise comparison; this comparison is done by using a ratio scale to indicate the strength of preference, followed by assigning a numerical score to each of the alternatives with respect to each of the attributes. The final outputs would be based on a combination of the weighted sum of scores [9, 50, 75, 79].

AHP is recognized as a powerful tool in solving problems. Its strength is in the systematic approach to structure complex multi-criteria decisions in several steps. Its evaluation is not based on historical statistical data; instead, it makes judgments based on comparative evaluation for multi projects against each other [50, 73, 79]. On the application level, there are several advantages of using AHP in project selection over other alternative project selection and prioritization techniques. AHP is a tool that provides practitioners with greater analytical capabilities to examine what-if scenarios [50, 55, 73, 74, 79].

AHP model gives decision makers some flexibility to choose and modify evaluation criteria, depending on the situations, and distribute them in many different levels regarding to their importance and related to the objective. It, however, has some potential drawbacks: 1) building the hierarchical model and weighting procedure is time consuming and it is hard to understand and needs a certain level of experience to develop the model [79], 2) AHP requires decision makers to weight each attribute against each other using some scoring values, and then score the alternative in the same way; this requires significant effort to achieve consensus between the managers who evaluate these criteria, 3) the weights and scores imply trade-offs between pairs of alternatives on different attributes, which may not be adequate. 4) when some of the attributes used in the evaluation fail to differentiate among the alternatives, the results of the scores will not be adequate and the true differences will not be clear [77, 79].

There is an ongoing debate among researchers about the performance and the applications of AHP. [69-71, 77, 116] have criticized AHP because it suffers from rank reversal: the rank of alternatives changes when another alternative, even a relatively unimportant one, is added or excluded from the set of options [55, 74, 77] or when a mutual criterion deleted if all alternatives share the same evaluation score for a criterion[77].

In its application, AHP requires mathematical effort, and once the hierarchical structure has been weighted, a change in criteria means making new comparisons and recalculating all of the weights [74].

Although AHP is a powerful model that is useful in gathering and processing knowledge for making decisions, this study shows that it is unsuitable for FFE screening decision.

2.2.2.3. Fuzzy Logic Methods

Fuzzy logic methods are another multi criteria decision tool derived from the fuzzy theory and is applied to help in making decisions in complex, ambiguous, and vague situations [18, 76]. A fuzzy set is 'fuzzy' in the sense that their elements have different degrees of membership to the set they belong to [117]. Mathematically, a fuzzy set can be defined by assigning a value to each possible member in a universe representing its grade of membership. Membership in the fuzzy set to a greater or lesser degree is indicated by a larger or smaller membership grade. Members' value, within a set, can range from zero to one [18, 117]. If x is a set of objects, then a fuzzy set A in X is a set of ordered pairs $A = (x, \mu(x))$, where x is an element of X in A, and $\mu(x)$ is degree of membership of x in A, and μ is a function that determine the degree of membership of the elements of the set [109, 117]. The major contribution of the fuzzy theory is its capability of representing vague data and allowing mathematical operators and programming to apply to the fuzzy domain [78].

Some application model use vague, everyday language like ‘equally’, ‘moderately’, ‘strongly’, ‘extremely, and ‘to a significant degree,’ as fuzzy values in order to quantify uncertain events and objects [74]. When linguistic variables are used, numeric values replace the linguistic values using specific functions later on in the process to calculate the final assessment value of each alternative to compare the results [8, 49]. Another applications of fuzzy logic in project screening combine AHP with fuzzy logic to make the judgment between alternatives more intuitive and eliminate the assessment bias caused by the pair-wise comparison process [76, 78].

Fuzzy logic thus enables decision makers to tackle the ambiguities effectively and efficiently, quantify imprecise information, perform reasoning processes, and reach decisions based on vague and incomplete data [18, 74]. Using the concepts of multi-criteria decision making and fuzzy logic, managers evaluate the criteria and the product ideas with regard to those criteria; instead of using numeric values to weigh these criteria, they use fuzzy measurements [27, 76]. A project that earns higher scores in comparison with other projects would be elected to be funded.

The fuzzy model has to be customized to fit with a company’s specific environment and the situation; this allows the company to use the criteria and the measurement that fits with its needs. This, however, is time consuming and needs a certain level of experience from mangers in order to work efficiently [36]. Applying the fuzzy logic require learning the fuzzy measures and the interpretation of these measures. The computation of a fuzzy weighted average is complicated and not easily done by managers, so, these calculations have to be computerized to increase accuracy and reduce the amount of time taken [76].

2.2.2.4. Conclusion on using Multi Criteria Decision Models for FFE Screening

One of the limitations of MCDM is its need for information on criteria, criteria weights, and criteria values. This information may not be available in the FFE and if it is, its collection may result in long time delays and high costs.

The main shortcomings of MCDM for FFE screening, however, is the operational usefulness; this is not just because it's built to be used by experts, but also because MCDMs suffer from a lack of transparency with regard to the logic of the method used to the decision maker. This happens due to several reasons; first, it may be hard to describe a new project with regard to a predefined set of criteria and even some very capable firms find that they cannot translate the new project to a complete scoring model and prefer to answer basic questions for screening, rather than using scoring models [9]. In addition, it is unlikely that the names, or labels, given to the criteria are interpreted similarly by all evaluators [64]. Furthermore, the choice and naming of criteria has to be done carefully to make sure that all important variables are considered and properly named and do not contradict each other [38].

Second, MCDM does not have a systematic approach to translate experts' judgments into weights (numbers or words) that are attached to each screening variable. Different people have different personalities that might affect the way they score.

Research indicates that some people are always optimistic, while some are neutral and their scores are always in the middle. Many scores are far from reliable and accurate, some scorers are easily swayed by group opinion, and some scorers are erratic [9]. All of these different types of personalities affect the weight of the criteria and how alternatives are judged; a perfect score for someone may mean 90 percent while it may be translated to 60 percent by others. Therefore, not having a clear systematic method of discerning these evaluations could cause ambiguity in translating the results [9].

Another shortcoming refers to the quality of the evaluation process, where MCDM treats the attribute weights and the performance scores of alternatives on each attribute in the same way. Research [55] suggests to evaluate the performance of an alternative on each attribute independent of other alternatives, therefore, the performance should be measured by using independent standards or common scales. Models that score projects in comparison with other alternatives would pick the best of the bad projects when a set of bad alternatives is proposed. In a case of having many alternatives with the same level of importance to the decision makers, the final scores of the alternatives may be too close to each other which will lead the decision maker to another dilemma, i.e., to pick one by guessing [74].

2.2.3 **Economic Models**

Economic analysis models are based on financial criteria and capital budget techniques. The most commonly used economic criteria are the net present value (NPV), payback period discounted cash flow (DCF), internal rate of return (IRR), and return on investment (ROI). There are many techniques that can help assist managers in estimating the market segments, and use financial criteria in making decisions [9, 82, 84, 118]. However, practically, the contribution of these models to R&D projects screening is little [9, 50]. Research found that there is a lack of use of financial criteria in the first two evaluation gates of the NPD process [25]. At the front end of proposal evaluation, there is some estimation of the financial criteria, depending on forecasting of market segments and knowing some expectations of the costs and revenues estimated based on previous experiences [38, 82, 84, 118].; however, when project is new, collecting reliable financial information, or estimating on require a long period of time, which makes it difficult to assist the decision makers at the FFE with accurate financial data. This makes the use of economic and market approaches less valuable at this early stage [9, 33, 39].

According to Crawford and Benedetto [9], the philosophy that calls for the financial analysis as early as possible to avoid wasting resources on poor projects is wrong because it leads firms to make complex analyses very early where the results are inadequate, which leads companies to unnecessarily kill ideas that would have looked great after further development. In addition, these economic methods consider only a single criterion which is the financial return, while R&D screening requires evaluation of projects with regard to many different criteria.

In addition, financial tools such as IRR, NPV, and DCF, suffer from a lack of flexibility, and fail to encompass uncertainties and to capture the strategic importance for investment [86]. Since financial criteria are important and need to be evaluated in order to make good decision, therefore financial analysis should be built piece by piece along with the product development, incorporating continuous upgrades and assessing the information as it becomes available [9], and the available information should be used in project evaluation [25, 82, 86].

2.2.4 **Decision Tree**

Decision trees are well established methodologies for decision analysis that involve structuring the problem into small sequenced tasks which represent different scenarios and expectations of future events. These tasks are analyzed and assigned numerical values, which represent estimated probabilities and confidence limits of each task or criteria values, and end up with consequential outcomes. These outcomes are estimated and compared by applying the principle of maximum expected utility to determine the best project [52, 83].

A decision tree can be customized and built for each individual case by choosing the criteria needed to be analyzed, estimating the values of each criteria and action. In case of limited accurate data, the decision maker can assign probability for uncertain variables and performances. Each project is analyzed and screened individually, not comparatively with any other project(s), and the final selection decision is made depending on the probability of the projects' outcomes. Constructing a decision tree, however, is time consuming and requires experience as well as analytical and statistical knowledge. When a problem is large and complex, developing a decision tree can be a complicated task because the tree grows exponentially and actions are hard to predict and interpret. In addition, changing criteria after the tree is built would mean making critical changes to the decision tree. All of this makes the decision tree an inflexible model for FFE project screening [83].

2.2.5 **Heuristics**

Heuristics are simple strategies or “rules of thumb” that humans employ for solving problems. They follow behavior and logic quite different than the consequential logic [119], minimize the amount of mental effort invested in making a decision [92, 95, 120, 121], and cannot guarantee optimal solutions [122]. Heuristics are part of a decision maker’s acquired repertoire of cognitive strategies for solving judgment problems [102]. They trade off the effort involved in making a choice against the accuracy of that choice [123, 124]. Instead of taking all available information into consideration, they focus on only one or very few attributes that suffice to discern decision alternatives in a particular situation. They are therefore characterized as ecologically rational [114] to contrast them against the concept of rationality as optimization.

In practice, most decisions are based on managerial intuition, rather than analytical approaches Consequently, managers heavily rely on intuition or gut feel in order to decide which project ideas to fund and to subsequently move to development and which ones to abandon [19, 22, 47, 125-127]. because managers are not familiar with more sophisticated processes, find them computationally too demanding [128], or do not have access to the type of input data that is required for advanced decision models [129 , 130]. Their decision approaches are based on single or very few decision criteria and are consequently largely at odds with the detailed catalogues of decision criteria for new project selection that are proposed in the literature [38, 50, 55, 74].

Although the reliance on managerial heuristics is recognized as a source of systematic decision errors [127] and has been linked to poor FFE outcomes [39], managerial heuristics also provide a quick and inexpensive way to clear the product evaluation system of unwanted ideas before they eat up resources for front end evaluation [9]. Furthermore early decision errors are assumed to have no severe consequences: If a good idea is wrongly rejected through managerial gut-feel, there are always other good ideas that can come in its place [29]. Also, if a bad idea is wrongly accepted, it does not cost much to mature it a little further and correct the mistake at a later decision gate that is based on more analytical approaches [29]. Heuristics are consequently accepted as an inferior, but nevertheless useful decision approach, as long as it limited to routine decision or very early screening decisions that can be revised later, and as long as decision makers strive to reduce their biases by making team, rather than individual decisions, by keeping records, and by providing sufficient background data [9]. However, for important and complex problems, with multiple and possibly conflict objectives and level of uncertainty rational decision models are greatly recommended [131]. Accordingly, the use of 'non analytical factors' or 'gut feeling' in project selection is widely criticized [37, 47].

New heuristics research demonstrates and advocates for the adequacy of heuristics as a shortcut decision rule that can approximate rational decision making: Astebro and Elhedhli [112] investigated the decision behavior of a panel of experts that predicts the success of entrepreneurial start-ups and model the experts' decision approach as a simple conjunctive heuristic that ignores some cues and weighs all other cues the same. This simple heuristic outperforms a statistically derived decision rule with optimal weights.

Research conducted by the author [132] investigated the performance of three F&F screening heuristics, as well as the performance of variations of a regression model, which serve as models for compensatory judgment behavior. Results show that two out of the three simple heuristics reach accuracies of over 80% for project selection and 70% for project rejection, while using as little as only one decision criterion. The best F&F model's performance is close to that of the best regression model, which correctly identifies 76% of the successes and 87% of the failures, but requires complex calculations. The best average performance was reached with a regression model that only considered four of seven decision criteria. These findings support the dominant view on managerial heuristics in front end screening that justifies the use of simple heuristics that focus on a small number of highly relevant criteria, rather than screening all available information to provide quick and no-cost decision gate that is "good enough" by the requirements laid out in the literature [9, 29].

From a theoretical perspective it is therefore possible that heuristics provide an appropriate method for FFE screening that helps decision makers to operate effectively when time and information are limited. Practitioners report that some decision makers are particularly successful at selecting good projects [10]. It is possible that these individuals use heuristics that perform as well as or even better than the best regression model, which did not outperform the best F&F heuristic by much. To date, however, the structure of managerial screening heuristics is unknown. Heuristic decision making has predominantly been investigated for less complex decision problems that have lower stakes than project screening, such size estimates for cities [92]. More research of "real world" front end screening behavior is therefore needed, to understand the decision making process managers' use and the way they evaluate criteria to enable us forecasting what decisions are likely to be made, and to help optimizing the front end funnels.

2.2.6 **Summary and Discussion- Part2: Decision Models**

The five most popular decision approaches for project screening and their application have been studied in part 2 of this chapter to assess their ability to fit the needs of FFE screening. The results of this review are summarized in **Error! Reference ource not found.** where columns represent the screening requirements that need to be met and the rows show the different decision approaches covered in this study. The table shows how well the screening method fulfills the requirements on a continuum from high (H) = fulfills requirements very well to low (L) = does not fulfill the requirement, except the codification column, which takes a *yes* value if the method has been well documented, and *no* if it is not. With regard to the level of information that needs to be collected about a project, we can see that MCDM and Heuristics models need relatively little data, because they depend on expert evaluation or weight on probability. The amount of information that needs to be collected also impacts the time needed to build the model and to come up with a decision. Heuristics have very low time demands, whereas economic models take a lot of time to build and operate. When assessing the flexibility to introduce new criteria or change existing ones without redesigning the problem, we found that analogy-based models and those built on financial data are usually fixed models that provide no room to introduce new criteria. MCDM and decision tree allow changing criteria but require recalculating all weights and probabilities in all levels. Heuristics provide the greatest flexibility. With the exception of MCDM and analogy-based models, all models are capable of evaluating a single project without comparison to other alternatives. For all of these models, it is either hard to develop or modify the model (you have to rebuild the decision tree and the MCDM hierarchy and redo all the calculation if you want to make any changes) or performing the calculation or reading the results need a certain level of experience and not easy to be used. Almost all models are furthermore based on previous researches and are well documented and codified. The only exception are heuristics, which little has been known about.

Two methods, MCDMs and heuristics, stand out because they fulfill almost of the requirements. MCDMs can deal with low levels of information, do not depend on historical data and are flexible to use. However, MCDM are comparative models that are designed to select the best alternative from a given set of projects, which makes them ill-suited for the evaluation of individual projects. Furthermore, they need certain level of experience about developing and using the model and time consuming.

Theoretically, heuristics show the opportunity to fit the needs of the FFE very well. However, since managers use their rules of thumb in an undocumented and possibly even unconscious way, little is known about which heuristics are being used for project selection.

Table 2.7 Evaluation for Potential FFE Screening Methods (shaded areas show the desired range)

Method	Information			Time			Flexibility In Changing Criteria			Independent Evaluation			Evaluate Single Project	Operational Usefulness			Codified
	H ↔		L	H ↔		L	H ↔		L	H ↔		L		H ↔		L	
Analogies		X			X				X			X	X		X		X
Economic Models	X			X					X		X		X			X	X
MCDM			X		X			X			X				X		X
Decision Tree		X			X			X			X					X	X
Heuristic			X			X	X				X		X	X			

Shaded areas are the requirement for fuzzy front end screening.
This evaluation takes place at a scale level from high (H) to Low (L).

2.3 Heuristics from Bounded Rationality to Ecological Rationality -The State of Art

Since early 1800s, heuristics have been defined as strategies that guide information search and modify problem representations to facilitate solutions [114]. Though heuristics are recognized for their ability to solve problems that cannot be handled by the logic of probability theory [133], in the past 40 years, they have been regarded as an inferior technique for decision making that is source of irrational decision behavior [114, 134-136]. Recently, behavioral decision making researchers like [92, 109] and managerial publications like [96, 137, 138], have demonstrated that some heuristics are highly efficient and can compete with complex decision models in some application domains.

The following section explores the different streams of research and summarizes the current state of art techniques in heuristic decision. Drawing from psychological and managerial research, this chapter starts with defining and explaining the origins of heuristics and cognitive maps (section 2.3.1). Then, (section 2.3.2) it presents a brief description of theoretical foundations and the key concepts of present day research on heuristics going from the ideal rational decision theory, contrasting it with behavioral decision that are based on the observation of real-world decisions by describing the bounded rationality theory [136, 139, 140] and heuristics and bias theory [134]. The rest of the chapter (section 2.3.3) represents the recent research on heuristics focusing on studying the structured fast and frugal heuristics, which are at the center of current research and potential useful approach for FFE screening.

2.3.1 **Definitions and Background**

In social science, heuristics are the general problem solving strategies that people apply for certain classes of situations [141]. They are often characterized as rules of thumb or specialized problem solving strategies that follow logic quite different than the consequential logic [102, 119].

The term heuristics in the industrial world does not exactly match the term in behavioral decision making. In industry, a heuristic is a mathematical model, with specified procedure, that is implemented in software and used to find the best solution for a problem in a well structured environment [90, 91] that humans have not been able to solve because of problem complexity or the need for calculation that lie beyond the capacity of hand methods and the cognitive systems [91]. In this research, however, we use the term heuristics to mean the behavioral problem solving strategy, not the computer heuristic.

Heuristics are sophisticated reasoning tools based on schemas (or mental databases) that experts hone over years of experience [96, 103, 138, 141] education, and through the process of latent (hidden) learning [138, 141]. Human brains use knowledge and experience to develop expectancy or cognitive representation of "what leads to what"; these representations are called cognitive maps [141]. The knowledge stored in these cognitive maps is not always applied instantaneously but may only be used and tested later, when there is a stimulus to perform: when a decision maker faces a situation that requires judgment, his or her brain summarize the situation at hand and identifies the important attributes. Then, it starts searching for a pattern between the new situation and what it has experienced or learnt before. After it recognizes the similarities, it starts to fill in the missing details and make assumptions based on previous experiences. Thus, the human cognitive system develops a ‘sense of what counts as relevant’ to identify the important attributes, the goals that need to be accomplished and the expectations. When the situation is not exactly the same as previous situations a person has experienced, the human cognitive system uses previous experiences to develop a sense of what could work [122, 138, 141]. This pattern matching is known as the Recognition Primed Decision (RPD) [138].

These problem-solving skills are not based on strategic analytical thinking; instead they resemble a mental map or schema generated out of a cognitive conclusion based on practices, experiences and emotional inputs gained over the years [126, 142]. The process of latent learning and pattern matching allows humans to learn and solve problems by insights. Different experiences in different decision environments determine different cognitive styles, which lead to differences in the quality of heuristic decisions [96, 138]. Over the last few decades, the usefulness and limitation of human heuristics is matter of considerable debate in the in the literature and has resulted in the development of competing decision theories.

2.3.2 **Theoretical Foundations and Key Concepts**

Early works on rational decision were mainly normative and describe how decisions should rationally be made. Later research was more behavioral focused and described how decisions are made. This lead to the insights that humans suffer from bounded rationality which causes them to use cognitive shortcuts and heuristics that do not follow the principles of rational decision [114, 134, 136, 139, 140]. The most popular theories that affected the way research looked at heuristics in the last six decades are summarized in the subsequent sections.

2.3.2.1. Rational Decision Theory

Rational decision theory, also known as choice theory or rational action theory, considers the utility theory, proposed by von Neumann and Morgenstern 1947, *as* the normative and effective theory for human behavior to seek the most cost-effective alternative to achieve a specific goal [143]. It assumes that the decision maker can identify the best solution by computing, with perfect accuracy, how different decision alternatives will pay out, and then choose the alternative that maximizes the value of outcomes [89, 144, 145]. Rational decision theory relies on an extensive use of mathematical logic to represent decision situations and model uncertainty through probabilities. It usually represents preferences with a utility function, the mathematical function that assigns a numerical value to each possible alternative facing the decision maker [144]. This choice is based on two assumptions about the future: a guess about the future state of the world which is contingent upon the choices the decision maker makes and a guess about how the decision maker feels about the future when he experiences it [119].

The strength of the rational approaches used in decision making is in their rigor. Working within the decision theoretic framework allows one to identify answers and to weigh the alternatives within the framework. These approaches encompass a substantial amount of educational content that is straightforward to teach and to test [119].

It did not describe how people make decision; instead it describes how people should make decision. Later researches accept the laws of probability and statistics as normative, but they disagree about whether humans can stand up to these norms and introduced the concept of bounded rationality [114].

2.3.2.2. Bounded Rationality Theory

In many real-world problems, the exact consequences of a choice are unknown; information about alternatives is also unknown or inherently uncertain. Uncertainty may exist because some processes are vague at the fundamental level, decision makers are ignorant of the driving mechanism which makes the outcomes look uncertain to them, or because of dependency on unexpected future events [119]. Furthermore, human logic doesn’t follow the utility function or the probability theory’s logic [119]. Rather than using formal methods or following systematic procedures, people usually make decisions by focusing on possible actions in the immediate situation and on the most obvious problems [119].

The realization that decision makers do not follow the principles of utility theory has led to behavioral decision researches, which are concerned about how people process information and make judgments. Studies have identified different cognitive and emotional limitations that bind human rationality and produce systematic errors [119]. They showed that decision makers do not consider all the alternatives, but instead consider only a few and look at them consequentially instead of simultaneously [119, 130, 146, 147].

All of these factors helped in deriving the concept of bounded rationality, which was first introduced by Herbert Simon [91, 136, 140]. Simon considered rationality as optimization, and decision making as a fully rational process of finding an optimal choice given the information available. Since decision makers lack the ability and resources to reach the optimal solution, they are partly rational [136]. To overcome this bounded rationality, people greatly simplify the choices available and seek a satisfactory solution rather than the optimal one, which Simon called 'Satisficing'. The satisficing strategy considered "optimal" if the costs of the decision making process and obtaining complete information are considered in calculating the outcome [136].

According to Simon [136, 140, 148], people cannot feasibly consider the optimal rational decision because of cognitive limitations of humans and structures of the environment that act as barriers. One of these cognitive limitations is related to the working memory: the human cognitive systems can process, remember, compare and recognize up to seven variables - plus or minus two - at the same time [141, 149]. When there is more variance, the human cognitive system becomes ignorant about what is going to happen. As a consequence, decision makers who try to make rational decisions will be constrained by limited cognitive capability and actions may not be completely rational, even with the best of intentions and efforts. [139, 148-151].

Humans can overcome this limitation by using decision judgment models built to fit with the mind's capacities rather than "fictitious competencies, because of the minds limitations, humans must use approximate methods to handle most tasks" [148] page 6. These methods exploit pre-existing structure and regularity in the environment [96, 152]. The second component of Simon's view of bounded rationality, the concept environmental structure, therefore explains under what conditions simple heuristics perform well or when the structure of the heuristic is adapted to the structure of the information in the environment [109].

2.3.2.3. Heuristics and Bias Theory

The discovery of bounded rationality has created a stream of research that was focused on uncovering human decision approaches and systematic errors. The theory of Heuristics and Bias proposed by Tversky and Kaheneman [134] page 1124, demonstrates that "people rely on limited number of heuristic principles which reduce the complex tasks of assigning probabilities and predicting values to simple judgment operations. In general, these heuristic are quite useful, but sometimes they led to severe and systematic errors."

Newer research in the field of heuristics is currently challenging this view. Heuristics and Bias views human inferences as quick-and-dirty, systematically biased and error-prone while probability inferences, that follow the theory of rational decision making, are not. This view relies on the laws of probability and statistics as normative, though humans cannot stand up to these norms [114, 153]. According to Tversky and

Kaheneman [134] page 18, "cognitive bias is not a result of motivation effects, or lack of experience: experienced researchers are also prone to the same biases when they think intuitively" However, experts do better than a non-expert because they rely on the reflective system [154].

The interpretation of bounded rationality and heuristics and bias represent the use of heuristics as making decisions that fly in the face of logic [141], and uses the term heuristics to account for "discrepancies between these rational strategies and actual human thought processes" [63] page 75. As a result, the view on heuristics has changed from indispensable cognitive processes for solving problems that cannot be solved by the logic of the probability theory [114], to something that almost opposite in meaning; heuristics refer to an unreliable method for make decisions.

2.3.3 **Recent Research on Heuristics: "Fast and Frugal" Decisions**

Gigerenzer [89, 114] argues that most decision research has not really followed Simon's ideas about bounded rationality by assuming that any simplified decision strategy that differs from the idea of rational decision making must deliver poor results. Consequently they have researched either how decisions are sub-optimal because of limitations of human rationality, or they have constructed elaborate optimizing models of how people might cope with their inability to optimize [98, 149, 155, 156]. In addition, the second component of bounded rationality, the environmental structure, explains that heuristics can perform well when the structure of the heuristic is adapted to the structure of the information in the environment. In these cases the heuristic can deliver good decision results while preserving scarce cognitive resources [157, 158]. The new call was to bring the environmental structure back into the study of heuristic decision, thus, a new focus on ecological rationality was born [109].

To adapt to the changing environment, decision makers have to make fast, frugal and good enough decisions. These real-world requirements lead to a new conception that proper reasoning must be ecologically rational" [109] page465. Ecological rationality exploits structures of information in the environment, and uses the right strategy to analyze this information and make a decision [114, 159]. The simplicity of heuristics make them well adapted to environmental change and can be generalized for new situations; such adaption will take advantage of the information available and fit with the new situation [103].

More recent research on heuristics attempts to investigate how heuristics evolve in response to specific decision environments, what types of heuristics exist and how they perform. To demonstrate the breadth of recent research that is interested in studying cognitive decision making heuristics, a taxonomy that categorizes and summarizes researches depending on their approaches has been developed (review Appendix A). In the next pages we review structured heuristics and their performance in artificial and real-life decision environment.

Recent research in psychology challenges the heuristics and bias view, and re-discovered heuristic decision making, and particularly so-called "Fast and Frugal" (F&F) heuristics, as a means to reach "good enough" decisions in complex situations that are characterized by multiple decision criteria, high uncertainty and time pressure [89]. This view has influenced popular business literature and has led to bestselling books on the value of managerial intuition [92, 96].

2.3.3.1. Fast and Frugal Heuristics

Fast and frugal heuristic characterize a set of ecologically rational rules of thumbs that allow decision makers to operate effectively in environments in which time, knowledge and computational tools are limited [114]. They are simple heuristics that researchers classify and structure into steps or rules. This research is concern about these structure heuristics that can be modeled, thus from now on the use of we are referring to fast and frugal heuristic. There are three general rules or building blocks for fast and frugal heuristics that comprise the principles by which the heuristics organizes the search for a solutions among a given set of alternatives and makes a decision [109]. These rules are :the search rule, the stopping rule, and the decision rule [92].

The search rule determines how decision criteria are applied to search for alternatives. The search will compare alternative with regard to important criteria until significant difference between the alternatives is found. When a significant difference is found the search stops, and the alternative that fulfills the stop condition is be chosen [109, 114].

The stopping rule determines when and how the search procedure should be stopped. Heuristic examination is limited rather than exhaustive. They do not study all available information, but instead they just take slices of the information important enough to help making the decisions [92, 96]. This limited examination makes heuristics different from the applications of utility theory. Utility theory applications have no stopping rules and integrate all pieces of information into the final decision, whereas heuristics keep decision makers from integrating multiple pieces of information [89, 95, 97, 105].

The decision rule determines how the search results -from research and stop rules - are translated into the actual decision. Decision rules are typically simple and require little additional information processing beyond the information obtained through the search. The clear stop rules, decrease the time used to make a decision [110, 160].

Fast and Frugal heuristics exploit structures of information in the environment [114] and thus allow decision makers to operate effectively without mathematical decision aids when there are high levels of uncertainty and limited time [89]. They can, however, be computationally modeled for evaluation and training purpose [89, 102]. These characteristics of fast and frugal heuristics that differentiate them from other decision models are summarized in Table 2.8

Table 2.8 Main Characteristics of Fast and Frugal Heuristics

Founded in evolved psychological capacities such as memory and the perceptual system
Ecologically rational; exploit structures of information in the environment
Simple enough to operate effectively when time, knowledge, and computational are limited
Precise enough to be modeled computationally

Powerful enough to model both good and poor reasoning

Gigerenzer, Goldstein, and others focus their attention on identifying the fast and frugal decision making heuristics by proposing computational models for heuristics, analyzing the environmental structure and testing their efficiency and effectiveness in various decision situations [89, 92-94, 103, 104, 111, 114, 121]. These studies often include a pre-defined set of heuristics, and assess which of these heuristics is the best predictor of subject's actual choices [107, 161-163]. They have identified two classes of F&F heuristics and many specific heuristics, which will be described in the following section.

2.3.3.2. Different Classes of Fast and Frugal Heuristics

Research has identified two broad classes of F&F heuristics; those that use a single reason, and those that consider multiple reasons at the same time.

A number of psychological experiments suggest that people often base their intuitive judgment on a single good reason [164]. Single, reason heuristics, also called lexicographic heuristics, describe comparative preferences where a decision maker infinitely prefers one option X to another Y. This class of heuristics based the judgment on the most important criterion that most validly predict judgments about alternatives and are applicable when the criteria do not share the same level of priority [89]. Lexicographic heuristics order the criteria in descending order from the most important criterion to the least and then select the alternative with the best value on highest priority criterion. In the case of a tie between two alternatives under the most important criterion, decision makers search the tied alternatives again according to the next important criterion, and go in the same order until finding a difference between the alternatives until decision makers can then choose a single alternative. Decision makers may still have to test most of the available criteria before they can find the distinguishing attribute that leads to a final decision. Variants of this lexicographic heuristics exist in the form of the, the Take-the- Best heuristic and Priority heuristic [94, 114].

Take-the- Best algorithm (TTB) depends on the rule of thumb that humans apply in daily life; this technique suggests, 'Try to Take-the- Best and ignore the rest.' Take-the- Best model is a non-compensatory strategy based on a single reason, and uses recognition heuristics to make rapid inferences about unknown aspects. The simple idea of this heuristic model is to treat what you know as important, ignore what you do not know. Starting by testing most important criteria, once you find a differentiation between the alternative (if one alternative provides the criteria and the others do not or you do not have enough information if alternatives meet the criteria or not) stop testing and pick the alternative that satisfies your criteria [59, 89].

The priority heuristic follows a simple rule where the decision maker has four reasons: the maximum gain, the minimum gain, and their respective probabilities. Criteria ranked from the most important, and search stops after finding a single distinguishing reason between the alternative but takes into account when criteria are interdependent and in conflict, e.g., when the criterion of high profits is in conflict with the criterion of low risk, decision makers order the criteria depending on the priority of the criteria in the given domain and the environment. One of the suggested ordering rule for these situation is to start with the minimum gain (and minimum risk), then probability of minimum gain, then maximum gain, because the reason for focusing on the minimum outcome is to avoid the worst outcome [94].

The search will stop immediately after first discriminating criterion is found. Following the concept of satisficing search can stop when an alternative surpasses an aspiration level. Where aspiration level is a fixed (not free) value, the decision maker will choose in order to stop the search if the alternative value meets or exceeds [155].

Elimination-by-Aspect (EBA) model proposed by Tversky [165], use the concepts of simple training, decision processes and a small memory load from psychological models. It is used to screen a group of alternatives quickly by eliminating those that do not match the requirements. Using this heuristic, after ordering the criteria according to importance, decision makers select and establish a cutoff value for each criterion. Then they start the screening by eliminating the alternatives that do not satisfy the value of the most important criterion. The heuristic then continues testing the alternatives according to the criteria that are left in their order of priority and eliminates those that do not meet the value of each criterion until only one alternative remains [93, 94, 108].

Another well-known heuristic is 'Categorization-by-Elimination.' Categorization requires determination of category membership of the alternative using the limited information provided about the future to make decision about this choice [166]. Many different models of categorization have been proposed in the literature [108, 166, 167].

Categorizing instances into clusters depends on the probability that an instance has certain features that allow it to be a member of a particular category [166].

Another class of heuristics is based on cumulative data instead of a single reason. Thus, it compiles the values of all or most of the criteria, in a simple way, to make a judgment. The Tallying heuristic, for example, gives all or some of the attributes the same level of priority and chooses the alternative that is supported by most reasons [114]. It disregards the relative importance of arguments and orders them randomly. To make a decision, decision makers compute the score of each option by adding up the number of its pros and then subtracting the number of its cons. The option with the highest score wins [93, 114].

While the Tallying heuristic does not take into account the relative importance of the criteria, Bivariate and Level-wise Tallying take into account that some criteria are more important than others and rank criteria in levels with regard to their importance. Then, alternatives would be tested with regard to criteria going from top to down, while computing the score for ach alternative by adding up the number of its pro's (at this level) and then subtracting the number of its con's (at the same level), until a difference level is reached. The preferred alternative is the one that presents the higher net score [102, 168].

2.3.3.3. Applications of Simple Heuristics

In the last ten years, many studies came out to test the efficiency of using heuristics in decision making. These studies tested these models' results mathematically and compared them with compensatory mathematical decision models.

Two different research designs exist: the first group compares the results of using simple heuristics in solving real problems, against well-known decision models in the field or against mathematical regression models as standard models free from biases [63, 88, 95, 101, 106, 112, 113, 148]. The second group tests the validity of the heuristics in laboratory tests [63, 64, 89, 107].

For the first group, in the medical field, studies took place to support diagnostic decisions. Katsikopoulos and Fasolo [95, 164], and Smith and Gilhooly [63] used the fast and frugal concept to develop a simple multi-attribute models and Yes/No decision trees to help caregivers diagnose medical problems and prescribe the right medication. Their models and decision-trees have been tested on simulated data, as well as on real cases. Katsikopoulos and Fasolo's F&F model registered performance accuracy in 72 percent of the cases; the logistic regression system achieved 75 percent accuracy, but took a longer time [164]. Smith and Gilhooly [63] found that the fast decision model which depends on matching heuristics, achieved almost as good results as the logistic regression model, but was faster and more flexible in making decisions about what medication should be prescribe for depression.

Outside the medical field, several studies tested heuristics models in forecasting outcomes [84, 85, 101, 106, 112, 113]. One of these studies tested the simple heuristics in comparison with the performance and information process strategies of experts and non-experts when predicting results in the 2002 World Cup soccer tournament [106]. From this experiment, that included 250 participants with different levels of knowledge, they concluded that participants who obtained more information about the teams did not outperform those who had no such information; this suggests that we need just a slice of information and not all of it to make a good prediction [106].

Bradley [101] used F&F decision models for early warning in order to forecast conflict escalation. Rather than drawing on dozens of indicators like the majority of early warning systems, which necessitates access to substantial amounts of data, most of which is highly aggregated and/or of poor quality, he used just three indicators. He used the results from this 'good enough' model to argue that both the conflict early warning and intelligence communities should consider the value of fast and frugal analysis.

Astebro and Elhedhli [112] tested the success of simple heuristics in forecasting commercial success of new entrepreneur projects. They tracked the success of 561 projects that had been evaluated in their early-stages by experts from the Canadian Invention Assessment Program (IAP); they found that the simple decision heuristics used to forecast projects succeeded in predicting 86 percent of the projects correctly. Experts predicted 82.6 percent correctly, while a log linear regression model correctly predicted 78.6 percent of the projects.

Albar et al. [132] modeled three commonly discussed Fast and frugal (F&F) heuristics for project screening (Take-the-Best, Tallying, and Elimination-by-Aspect) and employed a decision experiment to explore their performance as a means to clear the front end of product development of unwanted ideas. They found that the performance of simple heuristics may be better than commonly assumed: Two out of the three F&F heuristics reach accuracies of over 80% for project selection and 70% for project rejection and the best F&F model, Tallying, performs similarly to the best regression model.

Gigerenzer and his research group [89, 92, 93, 103, 104, 114] have analyzed the quality of the Take-the- Best (TTB) heuristic, one of the lexicographic heuristics introduced in the prior section, by asking which of two cities has a larger population. They tested the algorithm through simulation and compared the results to other algorithms that integrate all information and are considered to be rational, such as weighted tallying, which weighs and combines all alternatives, and a regression model. They found that the TTB algorithm drew as many correct inferences as the integration models, including the regression model, and performed substantially better than linear models. Gigerenzer tested TTB again, but instead of predicting the population of a city, he used it to predict the smallest dropout rate in a comparison of 57 high schools in Chicago, Illinois, based on 18 attributes [92]. From these two experiments, the simple heuristic of 'one good reason' proved better and generated faster results than evaluating all reasons in predicting what we do not know. On average, the TTB algorithm tested three attributes before it stopped searching and picked a choice which researchers found to be an acceptable choice. TTB performed on average as well as the regression models and used less time [89, 92].

Little experimental work has examined the validity of using Tallying [93]; some experiments examine the accuracy of the tallying heuristic by getting the average number of answers it correctly predicted and suggests that level-wise Tallying has (by far) the greatest descriptive validity, with an overall accuracy of seventy seven percent [168].

Gigerenzer explains the reason behind the efficiency of using simple heuristics as follows: “In uncertainty, a complex strategy can fail because it explains too much in hindsight. Only part of the information is valuable for the future, and the art of intuition is to focus on that part and ignore the rest. A simple rule that relies only on the best clue has a good chance of hitting on that useful piece of information” [92] page 85.

Some psychological research argues that not everyone follows the simple heuristics that fast and frugal models are based on [98-100, 110, 155]. For example, in an experimental setting Newell et al. [98] found that some people seek further information (and even pay for it), even after they find the distinguishing attribute. Their experiments show that 33 percent of the participants strictly follow the TTB heuristics, 46- 62 percent use some other frugal heuristics, and 25-38 percent violate the TTB fast and frugal heuristics. What works to make quick and accurate inferences with some people may not be the same with others, and what may work in one domain, may not work in another. Different environments can have different specific heuristics that exploit their particular information structure to make good decisions fitting with their situation [99, 155].

2.3.4 Summary and Discussion- Heuristics from Bounded Rationality to Ecological Rationality

Even though heuristics can lead to deviations from optimal decisions, recent psychological, social, and managerial decision research is increasingly interested in decision makers’ use of heuristics because heuristics result in accuracies close to more complex decision rules and seem particularly useful in difficult decision making contexts, especially when there is uncertainty over the future or when the decision need to be quickly made [63, 64, 89, 95, 107, 164]. Simple decision heuristics are therefore potentially useful for many kinds of managerial decisions and in particular for early project screening in the FFE, where the gathering of information for a full-blown multi-criteria decision model could result in long time delays and high costs, and decision errors are 'cheap' because they will soon be caught at subsequent checkpoints.

It is likely that managers use simple heuristics for project screening, which is frequently described as non-analytical, intuitive, and reliant on gut-feeling [20, 25, 40]. Since managerial heuristics evolve over time as a result of latent learning, at least some of these heuristics have to be well adapted to the decision environment presented in the FFE and useful at striking the right balance between decision costs and time on the one hand and decision quality on the other hand. If these successful heuristics could be identified, captured and computationally modeled, we may be able to develop decision aids for the FFE that overcome many of the challenges identified in Chapter 2.

Currently it is impossible to achieve this objective, because the heuristics expert managers use for project screening are unknown and no formal descriptions of screening heuristics exists.

2.4 **Literature Gaps**

This extensive review of the literature was conducted on three major related areas: firstly, new product development emphasizing on the fuzzy front end (Chapter 2.1), secondly, decision making approaches used for project screening (Chapter 2.3), and thirdly, heuristics decision (Chapter 2.3). A summary of the literature, as well as the currently existing gaps are identified in Table 2.9

For the fuzzy front end of new product development, current research simply states that screening is known to have an impact on project success; decisions are made informally, based on intuition. However, it is unknown when and how these decision are made, which criteria are used and which principles these informal decisions follow. Although researchers suggested some analytical methods for project screening, there was no evaluation system to evaluate the performance of decision making tools under different situations. This literature review grouped the most important features of FFE and used them to assist the decision methods, and close this gab. This evaluation found that the analytical decision methods in the study are not suitable for the FFE. Thus, the FFE needs systematic, transparent and efficient techniques for screening project concepts to make Go/No- Go decision as part of a series of evaluations or check points.

The alternative approach to screen new products at the FFE is the decision heuristics where researches show that managerial heuristics play an important role in early project screening. However, it is unclear how intuitive screening decisions are made, because there is little research about decision heuristics, and even less is known about how managers and experts use heuristics in project selection? Which heuristics are in use? Or, how they are used? This project is aiming to address this gab and investigate the managerial heuristics in screening new products at the FFE.

Table 2.9 Summary of Existing Literature and Gap Analysis

Topic	Emphasis on Existing Literature	Gaps in the literature
New Product Development	New Product Development as a mostly non-linear process that requires project evaluations at multiple stages	Improve knowledge about the screening process in the early stages of NPD
Fuzzy Front End	Fuzzy Front End has unique characteristics and requirements that distinguish it from other project stages. Because of the difficulties involved in evaluating projects in an early stage, managers heavily rely on non-analytical techniques. Decisions are therefore individual and undocumented and cannot be analyzed for improvement	Improved methods for early project screening that fit the characteristics and requirements of the FFE
Decision models for project screening	A variety of formal decision making approaches to evaluate new projects being proposed, though rarely evaluated against other methods or in real-world setting	Evaluation of the effectiveness of current projects screening methods for the purpose of FFE
Heuristics	Different heuristics are identified and modeled	Elicitation of heuristics that mangers use for

	In some situations, heuristics lead to good decisions despite a lack of time, information, and computational power	early project screening Modeling of managerial heuristics for early project screening Evaluation of the quality of managerial heuristics models in early project screening

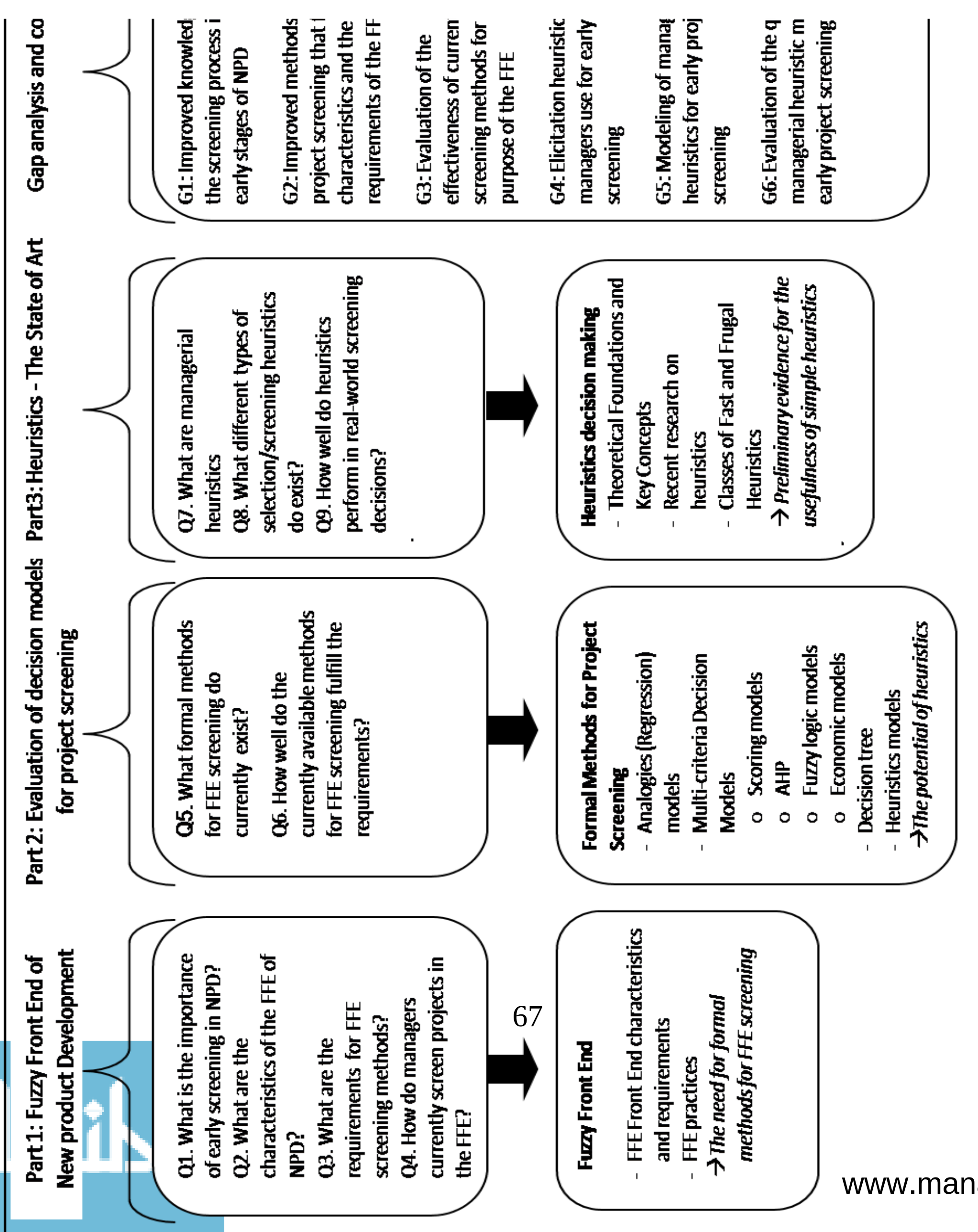
2.5 **Conclusion**

The above review of the literature and existing gaps made it clear that managers in the FFE usually face a situation where they have many proposed projects, limited budgets, and limited time to study the incoming proposals. A number of decision-theoretical models for project evaluation are proposed in the literature; however, their great contribution has been in the downstream end of the development process where data is available to feed complex decision models. Furthermore, these models have been underutilized as tools because they require data that new product development cannot practically provide [52, 58, 169, 170].

Currently, academic research fails to provide formal project screening models that fit the needs of the FFE. Instead, many front end decisions are based on managerial intuition, rather than analytical approaches. However, to date, little is known about the product screening heuristics managers use, which and how many decision criteria they employ, and if and to what extend their decision process resembles the ‘fast and frugal’ heuristics identified in recent psychological research.

After studying three areas trying to answer nine questions to identify the best suitable decisions tool to screen projects the FFE addressed in the literature, this chapter identified six gaps in the literature need to be addressed (Figure 2.3).

Figure 2.3 Summary of Literature Review and Gap Analysis



CHAPTER 3: RESEARCH OBJECTIVE, GAPS AND APPROACH

3.1 Research Problem

Managerial heuristics provide a quick and inexpensive way to clear the product screening system of unwanted ideas before they eat up resources for front end evaluation. However, managerial heuristics used for project screening are largely unknown. To date, little is known about the product screening heuristics managers' use, which and how many decision criteria they employ, and to what extent their decision process resembles the fast and frugal heuristics identified in recent psychological research.

3.2 Research Gaps, Goals and Questions

The objective of this dissertation is to advance existing knowledge toward a more complete understanding of expert judgment behavior related to screening projects at the FFE of NPD. Researcher is aiming to examining the way in which decision are made by highly proficient managers in screen projects at the FFE, and integrate these data to develop a heuristic decision model.

Four sets of research questions have been posed to achieve two goals: discover heuristics decision makers' use for FFE project screening, and structure the observed heuristics into systematic models (summarized in Table 3.1).

The four research questions are:

RQ1. What are the main objectives and constraints for FFE project screening? (Context of heuristics).

RQ2. What are the criteria used in the evaluation process? How are they ranked or weighted? How are they used to discern alternatives? (Structure of heuristics)

RQ3. Which patterns are observed to occur? (Patterns of use)

RQ4. How might a model be constructed from illustrated knowledge? (Mode heuristics)

Table 3.1 Research Goals and Questions

Research Gaps	**Research Goals**	**Research Questions**
Gap: Elicitation of heuristics that mangers use for early project screening	G1. Discover decision makers' heuristics for FFE project screening	RQ1: What are the main objectives and constraints for FFE project screening? (Context of heuristics) RQ2: What are the criteria used in the evaluation process? How are they ranked or weighted? How are they used to discern alternatives? (Structure of the heuristics) RQ3: Are similar heuristics used by different managers? (Patterns of use)

Gap: Modeling of managerial heuristics for early project screening	G2: Structure the observed heuristics in systematic models	RQ4 How can the identified heuristics be modeled? (Model heuristics)

By answering these questions, this research contributes in closing the research gap. It aims to identify the new product screening heuristics used in the FFE, and integrate a project screening model for the FFE. Eliciting and modeling the heuristics they use is an important area of research that will enable future researchers in management science and knowledge engineering to evaluate the current practices, identify the most successful ones, and emulate them in decision aids, expert systems and training programs [15, 66, 171, 172].

Since no theories exist to explain or predict the use of heuristics in the front end, the research follows an inductive design. However, the purpose of this research is not to develop a new theory, but to enable such theory development by providing a formal description of the screening heuristics expert managers use for the FFE. The same research objectives -the description of problem solving heuristics through formal models are at the core of the field of knowledge engineering.

Knowledge engineering captures and models expert knowledge in order to make it accessible through knowledge-based systems and building expert systems [14]. Knowledge engineering offers a variety of approaches for expert identification, knowledge elicitation, and knowledge modeling [14, 16, 171, 173]. These approaches are discussed in detail in Chapter 4.

CHAPTER 4: RESEARCH METHODOLOGY

4.1 Introduction

The primary focus of this research is to elucidate thorough descriptions of managerial heuristics. This can be achieved through a variety of methods evolved in knowledge engineering and cognitive science which have allowed investigators to discover the process and means of knowledge. These methods include observation, simulation, physiological, neuroscience, and experimental methods [174-177].

This research follows an inductive approach, rather than attempting to identify a predefined set of theoretically derived heuristics. It therefore applies Cognitive Task Analysis (CTA), which is a core method of knowledge engineering [14, 178, 179].

CTA is used to look into the black box of cognitive processes, and describe these processes formally through mathematical models [180]. CTA helps make expert knowledge accessible for designing practical aids, such as expert systems, decision support tools, and training manuals [14, 171, 173, 181]. CTA provides an extension of traditional task analysis techniques to yield information about the knowledge [182, 183].

A variety of CTA approaches have been used for knowledge elicitation, data analysis, and knowledge modeling, while ensuring the reliability and validity of research findings [14, 16, 171, 173]. CTA methods have been used for studying and describing the reasoning, knowledge, and strategies required for task performance in real world contexts [184-186]. The outcome of CTA methods is a description of conceptual or procedural knowledge, performance, objectives or standards experts use when performing tasks [177, 179]

CTA offers a variety of methods that can be grouped under three primary categories: 1) knowledge elicitation, 2) data analysis, and 3) knowledge representation. Although many people associate CTA with knowledge elicitation, which has received the bulk of attention, each of these three aspects is critical for successful cognitive research [15, 177, 184, 187, 188].

The interest in cognitive task analysis has increased rapidly in the last decade. CTA has been used in hundreds of research studies that require cognitive understanding, such as developing expert systems [189-191], and medical research [192-198]. System analysis uses CTA for identifying user requirements in system design, trainers and instructional system designers apply CTA methods to describe cognitive process and specify training requirements [183, 199]. Market researches use CTA to expose consumer decision processes and product use [184, 200]. Program managers, whether building new technology or improving an old one, look at the CTA as tools for understanding the cognitive requirement of operators on both individual and team levels [186, 201, 202].

Many researchers have studied the quality and the value of CTA tools [182, 192, 203, 204]. According to Lee [204], there are 318 published studies, in ten major academic databases, that used CTA between 1985 and 2003. CTA provides researchers with a strong pool of techniques to study cognitive judging. After studying the group of CTA methods, we chose the methods that would help address the four research questions. The rest of this chapter discusses these methods.

4.2 **Methodological Choices**

The methodological choices were made in pursuit of the research objectives. Three groups of methods are needed in order to answer research questions; 1) methods to identify experts; 2) methods to elicit expert knowledge; and 3) methods to analyze collected data and present results.

4.2.1 **Identifying Experts**

CTA typically focuses on capturing expert knowledge. Research should therefore collect information on the individual level from people who are subject matter experts (SME). Although true experts are scarce [138], they are also very knowledgeable, and therefore capable of uncovering a large number of problem aspects during interviews [184]. An expert is defined as a person with a very high level of proficiency and capability to make judgment decisions and discriminations that are difficult for most other people [171, 175, 184]. Experts have developed their skills through practice in their area of specialties and their performance and achievement have been tested again and again, which results in a unique skill set: As an example, senior managers are more knowledgeable with respect to strategic options [205], while middle managers have a more accurate and realistic view of the organization's available resources [206] and technological possibilities [207].

Because expertise is a result of practice, it is determined by the amount of time a person has spent doing a particular job [96, 171, 208]. The rule of thumb for selecting SME, based on Simon's 1973 studies on chess game players, states that expertise can be achieved after 10,000 hours of practicing (about 4 years). However, an expert typically does not only work on activities that directly relate to his expertise and may therefore need more time on the job to accumulate sufficient practice hours. Klein et al. [171] therefore state that 10 years on the job is sufficient time to achieve expertise, while other researches [14, 187], found that people can earn 25,000 hours of experience while they are still in their early thirties and thus much faster. Moreover, the work environment determines how much knowledge is accumulated. Klein et al. [22] in their research on firefighters observed that ten years of rural firefighting was not as valuable for skill development as a year or two of the same work in the inner city because urban firefighters are exposed to a wider variety of fires and higher rate of incident, hence giving the urban firefighter more experience in a shorter period of time.

Even though some minimum amount of time is necessary to develop foundational knowledge and skills, the actual accumulation of a set of experiences should also be taken into consideration. To identify experts, researchers therefore suggest setting a proficiency scale based on at least two criteria, one of which is typically experience on the job [187].

For the purpose of this research, four scales will be used to identify experts, namely: 1) minimum experience time limits of ten years or more [14-16, 42, 209], 2) minimum professional standards, such as degree requirements or licensing, relevant for the group of practitioners the experts belong to [210, 211], 3) measures of performance, such as the position of the experts or their recognition in their respective fields [14], 4) social interaction analysis; where peers with the same career recommend this person as an expert in the area [14-16, 209].

4.2.2 Number of Respondents and Cases

Because experts are scarce and expensive, most CTA studies rely on a very small number of respondents – as little as 2 to 3 [192, 212, 213] and no clear rules exist as to how many experts to include and how many cases to discuss with them. (Taxonomy of research using CTA methods with a number of participants is enclosed in Appendix B).

In inductive social science research, there also are no clear rules on the number of participants and cases needed to have sufficient data [214, 215]. The general rule on sample size for interview research is: when similar stories, themes, issues, and topics are emerging from the interviewees, a sufficient sample size has been reached [216]. Eisenhardt [215] argues that it is often difficult to generate theory or build a cognitive model, with much complexity, based on four cases or less, unless these cases have several mini sub-cases within them. On the other hand, the same research advises that with more than 10 cases, it often becomes difficult to manage the complexity and volume of the data [215]. Guest's study [217] that involved 60 interviews found that theme saturation was achieved after 12 interviews. Based on these findings, this research will conduct more than 4 interviews with several cases embedded in each interview and will continue to add respondents for as long as new insights emerge.

4.2.3 **Knowledge Elicitation Methods**

It is not enough to identify the right expert to carry out a thorough and valid cognitive research. One of the hardest aspects involved in cognitive research is eliciting experts' knowledge and skills. This is related to the fact that whenever a skill or knowledge has been highly practiced, it becomes tacit. As experts learn and practice their knowledge, they lose awareness of what they know and how to share this knowledge [218, 219]. Experts perform tasks without being aware of how or why they do what they do [220]. This type of knowledge needs effective knowledge elicitation methods in order to be extracted.

Knowledge elicitation methods are a set of methods used to obtain information about the knowledge, strategies, and judgments that experts use and the way they use them. They lead to knowledge models that show the contents of an expert's knowledge and how these contents operate. These knowledge models include facts, concepts, principles, and events that occur within the domain [184].

Knowledge elicitation is the first step of cognitive task analysis. Cooke [188] identifies three broad families of knowledge elicitation techniques under the CTA umbrella: (a) observation and interviews, (b) process tracing, and (c) conceptual techniques. Observations and interviews involve face to face meetings with experts where in-depth discussions take place, as well as observation of the participants while they perform the task under study [176, 177, 184, 221]. Process tracing techniques collect data about an expert's performance of a specific task either through think-aloud protocol or verbal self-report [222, 223]. Conceptual techniques produce structured representations of concepts within its domain [177] which been used for knowledge modeling or Concept mapping. Research conducted by Wei and Salvendy [224] introduces a fourth family of formal models, which use simulations to model tasks in the cognitive domain like using simulated games or situation to test cognitive behavior and reaction.

Within these sets, conducting interviews is the most frequently implemented method of knowledge elicitation [214, 215, 225-232].

An interview is an efficient method that is less complicated than making observations. Data collected through interviews is usually valuable and rich because it can capture information that is easily missed by other methods [216]. Another alternative method is one of the process tracing techniques, thinking aloud, which requires experts to report on their thinking processes during or after a task had been performed, by using personal report or thinking aloud while performing the task [175]. These two methods are described in detail in the following sections.

4.2.3.1. Interview

The three main styles of interview methods are structured, unstructured, and semi-structured. Structured interviewing has fixed content and sequencing. A semi-structured interview format is more flexible and allows the interviewer to switch to relevant issues as the dialogue progresses, whereas an unstructured interview is free-flowing [171, 172, 221, 226].

The typical approach for investigating behaviors is the semi structured, in-depth face to face interview, where the interview guide focuses on cases or incidents and highlights important factors and decision processes [221]. This dialogical technique has been widely applied in knowledge engineering and is called the Critical Decision Method (CDM) [14, 15, 171, 215, 226]. CDM is defined as "a retrospective interview strategy that applies a set of cognitive probes to actual non-routine incidents that required expert judgment or decision making" [171] Page 1. CDM has been used to examine non-routine and challenging events because stories and incidents provide great potential to uncover elements of expertise related to cognitive phenomena [184]

CDM is an interview-based method that uses open-ended questions to motivate respondents to remember specific decision situations, describe these situations, discuss their judgment process, and decision making strategies.

The interview guideline may additionally apply a set of probes to encourage the expert to explicitly discuss his or her judgment process and reflect on his or her own system of decision making strategies [171, 172, 226, 227].

CDM makes use of the fact that experts often refer to illustrative or prototypical examples of past cases when asked to justify or explain their decisions or actions. They like to 'tell stories' because a great deal of an expert's knowledge is remembered in the form of previously encountered cases [233]. In CDM interviews, experts are prompted to retrieve past events from memory, for example by asking the interviewee to select the last situation where she or he has had to make a decision of interest to the researcher. If the participant cannot immediately remember a decision making incident, then several scenarios are briefly proposed to encourage the participant to pick the most relevant one and start discussing the situation and his or her decision making process [171-173, 215, 221, 225]. For many people, drawing a diagram is necessary to refresh their memory and help in reconstructing the key features of a situation [171, 172]. Therefore, participants are allowed to draw diagrams while explaining the process or in responding to probes. In addition, participants are encouraged to share any personal notes, documents, or journals they have been using in their decision making process.

In most knowledge elicitation projects, researchers rarely have two hours with a domain expert, and in some situations do not have more than fifteen minutes to conduct their interviews [171, 172]. For practical purposes, the inquiry is therefore considered complete when the interviewee tells his own story and point of view, and gives as many different perspectives as possible, which are often presented in stories, examples, conversations, metaphors, and analogies [231, 234].

The use of retrospective protocols of stories and incidents allows research on naturalistic tasks that cannot be emulated in experiments and avoids any influence of the researcher on the respondent's actual decision process. It is furthermore suitable for the examination of non-routine events that cannot be easily observed in the field because they occur in an ad-hoc way [15, 171, 172, 178, 226, 235, 236]. To avoids the risk of recall biases that could cause respondents to forget some past decisions or to remember decisions as more structured than they actually were, a second methodology will be applied to collect data. Process tracing approach allows observing participants while they are performing a task, witness and describes behavior in a work context and unveils a greater amount of specific (task-related) information than interviews as discussed in the following section. It does, however, require that the researchers know when the task will be performed and thus cannot capture ad-hoc situations. It therefore often relies on specifically prepared 'test cases' that can create an artificial evaluation situation. To offset the disadvantages of each method and minimize method biases, we applied both CTA approaches.

4.2.3.2. Thinking aloud procedure

Protocol tracing provides a viable alternative technique to the interview, for knowledge elicitation. Thinking aloud is a commonly used method that has been widely accepted as a useful foundation for cognitive research [172, 222, 237]. During the thinking aloud procedure, participants are asked to actually perform the task and screen project proposals while describing the steps required, or essentially to think aloud. The task performance may actually be a real-world task or a set of specifically prepared test cases that reflect the scope of activities the researchers are interested in. The latter approach has been successfully employed by developers of expert systems to elicit experts' knowledge [238, 239].

The advantage of this process tracing technique is being able to witness and describe the participant's expert behavior while performing the task in a work context and potentially gathering the verbalization of cognitive activities, which generate a greater amount of specific information than the interview [226]. However, in the case like

FFE where decision take place ad-hoc, no predicting for the time or place the task will take place; this method often relies on specifically prepared ‘test cases’ that can create an artificial evaluation situation.

For quality control research, Crandall et al. [178] suggest to compare the notes of the researcher’s team members if there is more than one researcher, or audio recording and transcribing the interviewers and observations of participants while they think aloud.

4.2.4 **Data Analysis Methods**

Once expert data is elicited, it needs to be analyzed and synthesized into knowledge models. Methods for analyzing and representing CTA data, however, have not received the same level of attention as those for knowledge elicitation [178]. Three commonly used data analysis methods in CTA are: Work Domain Analysis (WDA), which results in the functional description of a work system, Cognitive Mapping, which results in a visual map that shows key concepts of a knowledge domain and their connections, and the Critical Decision Method (CDM) [14, 177-179].

Work Domain Analysis (WDA) builds a representation of an entire work domain. It performs a functional analysis of a work domain to build a representation of the entire work in terms of levels of abstractions, with each level being a distractive type of constraint. This information is represented in an abstraction decomposition matrix. The matrix captures information elicited from experts regarding their goals and reasoning, and then combines them into a bigger context to represent the collaboration between all entities and organizational goals. A WDA matrix shows the relationships between entries on the same level and those on higher and lower levels and how functions and needs meet. WDA has most frequently been used to describe the structure of human machine systems for process control, but it is now finding interest in the fields of analysis and design of complex systems [14]. Thus, it is not suitable for the purpose of this research about illustrating the decision heuristics from collected data.

Concept mapping is a very strong tool that been widely used for knowledge modeling of domain concepts and to represent the relationships among concepts using diagrams, called concept maps. Concept maps are diagrams that are used to represent and convey knowledge. These Concept maps can be linked together to perform a knowledge model. Knowledge models are repositories of experts' knowledge that can be used for training purposes, sharing organization knowledge, and also provide infrastructure for project management. and for any other application [14, 178]. Although can be used to analyze incident selection, Concept mapping is concern about the elements in the domain and how to connect these elements together in the domain stature, Thus, it does not fit with the purpose of this research of analyzing individual cognitive behavior.

Critical Decision Model (CDM) is also used as analysis technique constructed around participants stories. From these stories researchers can extract information about attributes, rules of thumb that participants have used, types of decisions they have made, and their decision behavior. In order to understand the decision requirements and scenarios, the process of coding data must take place. This process of data coding related to CDM method is called Protocol Analysis [178]. During the analysis process, each and every statement is coded according to some sort of coding sequence or scheme that reflects the goal of the research [171, 174]. Codes are defined as "tags or labels for assigning units of meaning to the descriptive or inferential information compiled during a study" [240] (Page 56). Since this research is concern about individual judgment and collect data for knowledge elicitation is relying on telling stories, CDM along with protocol analysis is a suitable analysis method for this research.

4.2.4.1. Process Analysis and Data Coding

Coding interviews and extracting contextual information is a lengthy and involved phase of analysis [178]. In traditional protocol analysis, each and every statement is coded according to some kind of coding scheme that reflects the goal of the research. There are a number of alternative coding schemes can be used for protocol analysis. However, which coding scheme is chosen depends on the task domain and the purpose of the analysis [178].

Table 4.1 Phases of Data Analysis

Phase	Objective	Task
Preparation	Get familiar with the data set Insure the quality of data and transcripts Use collected data into a structural process inquiry	Records transcriptions completed and reviewed Prepare interview, transcript, notes and observation data to be analyzed Project issues and questions reviewed Develop the coding scheme
Coding Data	Examine Pieces and parts Classify the information Update the coding scheme	Protocol Analysis Procedure to: Identify elements and segments Coding data related to the coding

Phase	Objective	Task
	Identify central decision questions	schemes Adding new coding nodes as necessary Abstract decision questions and decision nodes
Discover Meaning	Merge nodes and gather pieces' of meanings Identify most important decision criteria Identify decision process Review for quality assurance	Review using the updated coding scheme Structure, integrate and compare pieces Ranking, rating, and group contrasts Draw flow charts Review all coding for quality assurance
Integration & Key Finding	cross cases pattern information integration Identify decision behavior Make meaning visible	Illustrate, compile and compare. Compare against decision heuristics research Integrate information to identify and model decision procedure

The goal of the first phase of the analysis is to help get familiar with data and identify coding schemes that will be used in the analysis. Codes can be theory driven and developed from existing theory or concepts, data driven and developed from the raw data, or they can emerge from specific project goals and questions [178]. Once codes have been created, they are organized to develop a codebook. A codebook is a set of codes, definitions, and examples used to guide in analyzing qualitative data and provide a formalized operation of the codes [241].

Audio recording and transcript will be reviewed and coded according to the identified codebook, and new codes will be added as needed. The goal of coding the interviews is to abstract information about the nature of the project that is contained in raw data. Each coding node represents a meaningful statement abstracted from the interview.

Transcripts' statements should not only be categorized with reference to listed coding categories. Codebooks might be more complex and contain sub categories [178], but they should also be analyzed collectively though a higher level of coding to enable researchers to identify any connection between codes [241]. Thus, all data should be reviewed again using the updated codes aiming to structure, integrate, compare pieces, and group contrasts [178]. The transformation of meaningful statements into codes is useful to understand the behavior and answer research question. Thus, the final phase would integrate and find results by applying cross case comparison, looking for patterns, and integrating pieces to come up with final results. Descriptive flowcharts and diagrams might be used as needed to represent the results.

This lengthy data analysis approach- starting from defining coding schemes, building the codebook and going through coding and integration processes- attempts to capture in great detail the research information from rich qualitative data.

Documenting the analysis process is critical for quality assurance [178]. Since it is challenging to keep track of the process, QSR NVivo the qualitative data analysis software will be used to keep track of the coding and the modifications.

4.3 **Ensuring Reliability and Validity**

In qualitative research, validity cannot be determined by correlations, statistics or with scientific criteria associated with the experimental design. Instead, it is measured by ensuring the reliability of each step of data collection and analysis, and by determining whether other researchers can meaningfully extract the same insight from the data [228, 242, 243].

Thus, validity threats has been identified and ruled out after a tentative account has been developed as suggested by research [244]. In the context of this study, validity gets at the question of whether the theoretical framework and the heuristics accurately capture the relevant aspects of human behavior [245]. Table 4.2 lists the validity threats which were identified and addressed during the course of the research.

This research is not using a standard laboratory for knowledge elicitation; instead, it gathered the information from real experts about their screening experience of real projects. Standard laboratory studies usually do not use highly experienced participants, and tend to focus on the analytical skills needed to evaluate options. On most occasions, "they leave option generation as something of a mystery" [181] page 14. Campbell [246] described this approach as random generation of options, followed by analytical methods to identify and select the best option, which does not happen in early screening of new products in real life setting. Thus, we used two knowledge elicitation models to collect data.

Like other cognitive research, we cannot determine absolutely to what extent were the participants simply telling the accurate account of each process. However, we developed a number of techniques designed to improve the accuracy and consistency of the interview data. Interview guide developed to focus probes on the direction of obtaining a rational deliberation description. The interview guide was developed in an attempt to balance between two objectives: keeping the interview as unstructured and as free from interviewer bias as possible, to allow respondents reflecting freely on their experiences and tell their stories, and at the same time, keep the collected data clear of unrelated information. A pilot interview, which lasted for an hour and forty minutes, showed that the interview questions and technique were capable of eliciting knowledge about the subject. Thus, interviewer directs the respondents to focus on those elements related to screening projects by asking them to give examples for previous projects. Furthermore, we believe that asking experts to report aspects of their decision processes is different from asking participants to consider on their motivations in an unfamiliar laboratory environment. This procedure seems to be successful, because “it seemed to establish the interviewer as a listener rather than as an interrogator” [181] page 20, which increases the cooperation [247].

In addition, a second method, thinking aloud, has been used to observe screening projects from the beginning to end. Although, verbal protocols as a data collecting have a long history in psychology, it has sometimes seen as an invalid variant of introspection. In our study, we tried to avoid the propensity for participants to speculate by asking them to speak about what they were actually seeing, and thinking at the moment. Using thinking aloud eliminates any threats that respondent forget some details or could not retrieve all facts when telling the story. To ensure the quality of the method, three trial of thinking aloud procedure took place to ensure the quality of the technique before we applied it with expert. Rich data were collected on both practice of the interviewee and on the thinking aloud technique.

Criteria have been defined using definition used in the literature to look up these criteria; in addition, two PhD candidates will be asked to review the definition of these criteria. To ensure reliability, as suggested by research [178, 248], all steps of the research were carefully documented, all interviews have been transcripts, codebook have been clearly described and kept up to date and reviewed regularly.

The structure and analyzing approach are clearly defined. Two interviews (one from each round) will independently be coded by a second researcher to check for inter-coder reliability, as suggested by researches [214, 221, 234].

Table 4.2 Validity Threats and Countermeasures

Validity Threat	Study Countermeasure
The respondents might be unrepresentative	Build the proficiency scaling based on at least on four methods to select SME
Interview setting might not be efficient to illustrate the knowledge	The pilot interview, which lasted for an hour and 40 minutes, showed that the questions and technique were capable of eliciting rich data Three pilot tests of thinking aloud technique show the efficiency of the thinking aloud technique in collecting data and observing the decision process
The information might be systematically biased	Two methods have been used for collecting data to avoid methodology bias All interviews were recorded and transcribed to insure catching what participants said
The decision settings might be artificial and unrealistic	Collect context-rich data though telling stories and screening real proposals
The researcher might influence the informant's decision process	Collect retrospective data on decisions which were made in the past
The informants might selectively recall past decisions as being more structured than they actually were	The second round of data collecting, observed screening while the process is happening

Classifying criteria or indicators used in the evaluation process were vague	-Used the decision criteria and heuristics definitions from the literature to build a clear codebook -Add look up words and example to the codebook to define the indicators -A group of experts confirmed their agreement with the definitions
The researcher might arrive at invalid or premature conclusions	- Compare the decision process cross cases - To ensure the inter-coder reliability: A second researcher code two interviews (one from each round) A random subset of the code have been coded independently by two different researchers, - Compare the decision process with other studies

Quite apart from the issues relating to adequate memory of the responded when describing the judgment process, the question of whether self-examination is a valid means of collecting data about mental processes?, could be raised. Researches [181, 221, 231] believe that introspection is a legitimate source of data. However, we do not consider it as a direct access to cognitive processes; instead, we consider it an exploratory method -with its own limitations -that capturing the context of phenol's perspective and describe the decision making process in a real life. The attractiveness of knowledge elicitation methods is that they offer a rich source of data for building hypotheses. "The ultimate validity in relation to any proposed cognitive model will be judged by the usual standards of scientific acceptability" [181] page 188. Thus, all results will be checked against it are other researches both on decision behavior as well as new product screening fields.

4.4 **Summary**

As a core method of knowledge engineering, CTA is used to look into the black box of cognitive processes, and to describe these processes formally through models that make expert knowledge accessible for designing practical aids, expert systems, decision support tools, and training manuals [14, 171, 173, 180, 181].

Within the CTA framework, two knowledge elicitation techniques were chosen to for this research: Critical Decision Method and Thinking Aloud. The use of retrospective protocols of stories and incidents allows research on naturalistic tasks that cannot be emulated in experiments and avoids any influence of the researcher on the respondent's actual decision process Thinking aloud is a process tracing technique that observes participants while performing the task and thinking aloud. The approach allows researchers to witness and describe behavior in a work context and unveils a greater amount of specific task related information. To avoid the risk of recall biases, and offset the disadvantages of each method and minimize method biases, we applied both CTA approaches. Protocol analysis multi-phase approach is commonly used for coding data in cognitive researches, to obtain knowledge about decision screening behavior. Quality control was addressed to overcome the shortcoming of each method and to ensure the quality of methods in all stages of the research.

CHAPTER 5: DATA COLLECTION AND ANALYSIS

5.1 Introduction

As discussed in the prior section, this research follows and inductive approach and applies Cognitive Task Analysis (CTA) to capture decision heuristic for screening projects at the FFE, on the level of the individual. For the purpose of this research, two knowledge elicitation techniques within the CTA framework - CDM and Thinking aloud - were chosen and applied sequentially to two different groups of respondents (Figure 5.1). Within each method, data collection and initial analysis occurred concurrently before the insights gained from each method were compared and integrated.

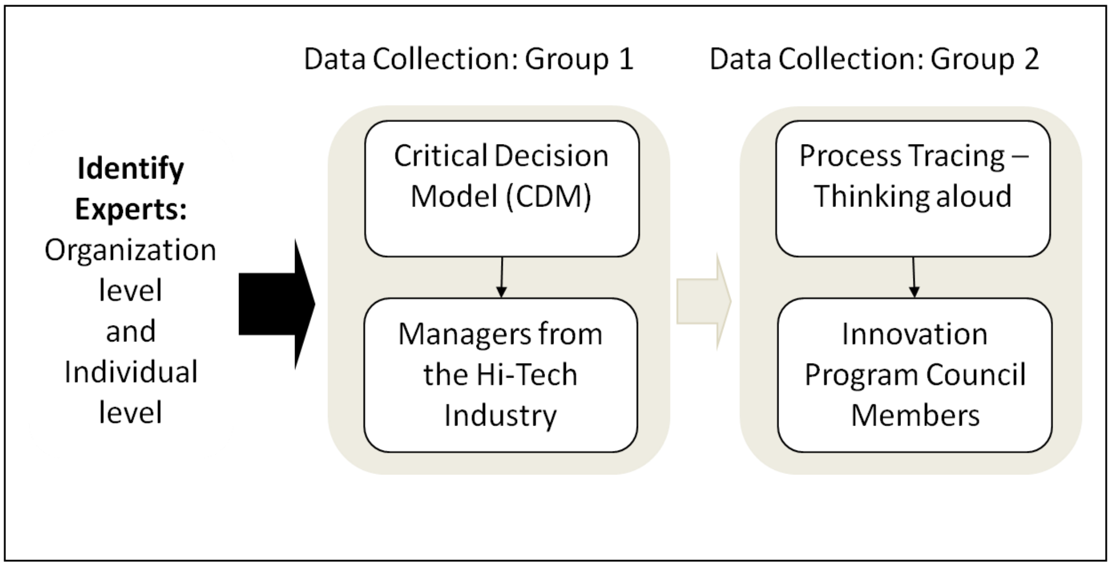


Figure 5.1 Data Collecting using Two CTA Methods

The following sections describe the specific research steps and results.

5.2 **Research Participants**

5.2.1 **Subject Matter Expert**

Although the identification of experts is not considered much of a problem in the practice of experimental psychology and in expert system development and often occurs quite ad-hoc [215, 239], in contrast, this research employs a multi-criteria proficiency scale that is both domain and organizationally appropriate [14] to identify the Subject Matter Experts (SME). Respondents were selected according to four proficiency scales, (explained in more detail in Chapter 4) namely; experience, formal qualification, authority as a measure of performance, and social interaction analysis. The four scales are presented in Table 5.1. To be included in our research, respondents had to fulfill the proficiency standard for a minimum of three of the four proficiency measure.

Table 5.1 Proficiency Scale Used in This Study to Identify Experts

Scale ID	Proficiency Scale Method	Proficiency Measurement	Reference
SC1	Experience Time Limit	Have minimum of 10 years of working experience	[32, 178, 198]
SC2	Professional licensing, Education Degree	Have a minimum of a B.A. degree in engineering or business	[210, 211]
SC3	Measures of Performance	Participants are authorized to make promotion decisions for projects, commit resources to them and are responsible for the	[14, 208]

		outcome of the decision	
SC4	Social Interaction Analysis	Peers have suggested this person as expert in the field	[14-16, 209]

5.2.2 **Participants for CDM Interviews**

The selection of respondents for CDM interviews followed a two-step process: The first step requires identifying companies that employ decision makers who screen NPD projects and can thus serve for the purpose of this research. The second step is to sample suitable respondents from these companies through phone or emails.

Since the research is interested in the heuristics used by individual decision makers to screen NPD projects, differences among the respondents' companies, with regard to culture, location and size, are irrelevant. However, only companies with an active NPD program can be expected to regularly screen projects in the FFE. Therefore, only companies that are active in new product development were contacted. Six participants in our sample belong to semi-conductor companies with R&D intense industry that report new product releases on their company websites and/or annual reports. The rest of the sample works with companies that belong to sectors with low R&D intensity, such as designing and manufacturing new products, and employ managers with relevant screening experience. These organizations can be expected to experience the FFE challenges and constraints described in early in Chapter 2 .

Tens of short telephone prescreening and a hundred of emails have been sent targeting experts in order to identify decision makers who are authorized to make promotion decisions for projects, commit resources to it, and are responsible for the outcome of the decision. This focus excludes people who screen their own project ideas before sharing them with their superior or other people in the company, because these experts do not formally commit resources to the screening activity and cannot promote the project. However, this focus includes people who do not have the discretion to allocate resources and promote projects on their own, but do so as part of a group decision in, for example, project selection committee.

Thirty two managers employed in high.-technology companies with active R&D pipelines and hold managerial positions, such as General Manager, President, VP of R&D and R&D or project manager in R&D, directly approached by the researcher. Because of the sensitivity, work load and travel commitment regard to their positions, only 9 of the 32 positively responded and voluntarily accepted to participate in this research. In these functions, all respondents are typically authorized to make promotion decisions for projects, commit resources to it, and are responsible for the outcome of the decision. In one case the decision maker did not have the discretion to allocate resources and promote projects on his own, but does so as part of a group decision in a project selection committee. All participants for this round fit the proficiency scale (Table 5.1).

5.2.3 **Participants for Thinking Aloud Process Tracing**

Thinking aloud requires that the researchers know when the task will be performed to observe it, however, new product screening happened ad-hoc, time and place are unpredictable and researcher might wait for weeks before he observe any new product screening, To overcome this issue this technique often relies on specifically prepared 'test cases' that can create an artificial evaluation situation. Researcher had a great opportunity to observe a real setting of screening projects proposal. Members of a university committee, named Innovation Program Council who evaluate project proposal for innovative student projects in engineering accepted to participate in the research. They screen project proposal individually then as a group, accepted projects receive funding and other resources, such as faculty expertise. The selection process consists of several steps: in a first step, each council member selects the projects he or she wants to include in the council's selection process by giving a grade on a 5 point scale. The scales are not used to rank order the projects and there is no set limit of the number of projects that a council member can promote. However, projects with poor average scores are not included in the further review, unless a council member strongly recommends their inclusion. The council members thus serve as gatekeepers. Based on the initial screening, projects are selected for presentation to the council. After the presentation the council decides on supporting the project or rejecting it.

Out of the six members of a university committee have been contacted, three accepted to participate in this research. These respondents were experienced engineering professors who had previously served on the Innovation Program Council, as well as on other project evaluation programs (e.g. for NASA and Venture Capital panels) (see Table 5.2).

Table 5.2 Summary of Research Participants' Qualifications

Group	Respondent Summary		Proficiency Scale	Length of Interview
Group 1	1	GM of Enterprise Platform Server Division in high semi-conductor company 26 years of experience	SC1, SC2, SC3, SC4	45 Min
	2	GM of industrial automation companies, design and tests new products, worked as a manager in R &D 22 years of experience	SC1, SC2, SC3, SC4	45 Min
	3	Process Development Manager at a High-Tech Company 14 years of experience	SC1, SC2, SC3, SC4	40 Min
	4	Vice President of R&D in semi-conductor company 22 years of experience	SC1, SC2, SC3	55 Min
	5	A Project manager in semiconductor h company severed for 5 years on new business creation team 23 years of experience	SC1, SC2, SC3, SC4	40 Min
	6	President of a strategic business acceleration and venture funding company, Licensing and Business Development 15 years of experience	SC1, SC SC3, SC4	45 Min

	7	Technology Development organization and has been responsible for product developing 17 years of experience	SC1, SC2 SC4	35 Min
	8	Global Sourcing & Procurement Company 6 years of experience	SC1, SC2, SC3	30 Min
	9	R&D manager at a semiconductor company 25 years of experience	SC1, SC2, SC3, SC4	25 Min

Group	Respondent Summary		Proficiency Scale	Length of Interview
Group 2	10	Associate professor had experience as an advanced development engineer, served in many panels for project evaluation 23 years of experience	SC1, SC2, SC4	50 Min
	11	Assistant professor, Vice President at an energy company, designing and managing appropriate technology programs 11 years of experience	SC2, SC3, SC4	30 Min
	12	Associate professor, serving in screening projects for several Venture Capital institutes 20 years of experience	SC1, SC2, SC3, SC4	70 Min

5.3 **Data Collection**

The objective of the data collection step with CDM and Thinking Aloud Process Tracing was the capture of verbatim interview responses on audiotape, but as discussed in Chapter 3, the interview techniques differed in both data collection steps.

5.3.1 **Using Critical Decision Model**

A semi structured interview was developed for this study, based on Flanagan's [249] critical incident method, to start the conversation and guide the participant to focus on the attributes that most affected the decision, recall and reflect on one previous project. Interview was designed with attention to keep balance between two different objectives: keeping the interview free from interview bias as possible by allowing managers to represent their perspective freely, with avoid collecting unrelated information; which will be impossible to classify. Interview questions have been tested on 45 minutes, pilot interview, to check the efficiency of the method for collecting data for related this research (see Appendix C).

Prior data collecting and interviewing the experts, the purpose of the study, and confidentiality agreement were discussed with each participant. Informed Consent Form (Appendix D) was sent to all of respondents by email prior the interview. Participants knew they were being studied, knew the type of information we were trying to obtain and they accepted to serve for data collection. All participants were assigned identification code, names of participants or their companies were not used in any of the transcripts or other data. There was no deception involved. Each interview took from thirty minutes to an hour in length. To avoid missing any details or useful information, interviews have been routinely recorded, as long as participants accepted. For one interview that did not get to be recorded, interview note has been taken during and after the interview.

Interviews were conducted using the guideline; we asked respondents to recall and reflect on one previous project, prompts and questions were used to the minimum to clarify information or ask about more details. All questions were open-ended to give a space for respondents to reflect on their experience.

5.3.2 **Using Thinking Aloud Process Analysis Technique**

For the process tracing, the three council members who accepted to participate in the research have been contacted and asked to evaluate the proposals in front of the researcher, think aloud while they are evaluating the projects, and give their comments about the proposals. The same procedure (as round one) of explaining the purpose of the project and sharing the consent form took place. Two council members were observed while they were screening a pile of project proposals. The third council member preferred to review the projects without thinking aloud but commented on each proposal and his screening decision in an interview that followed immediately after he had finished the screening; since he still had his comment on proposals, and remembered the details, he explained his screening process from the beginning to end. All statements were recorded. In addition, the interviewer took notes.

5.4 **Data Analysis Approach**

This wealth of in depth material needed to be analyzed in such a way that the concepts developed and theoretical analysis would reflect the data well. Data analysis attempts to capture in, as rich detail as possible, the evaluation process from the point of view of the expert managers. Each story or example of a project – provided by the respondent-would be classified as *decision case* and used as the basis of the analysis. Researcher attempt to study the criteria been evaluated to make the decision, the process of the evaluation and any internal or external factors affect the decision making. Data analysis was done using the qualitative data analysis software, QSR NVivo 9, and it took place in four overlapped phases (see Figure 5.2).

During the first phase the audio recording were transcript and reviewed. The researcher went through every transcript; breaking it down into discrete chunks to facilitate analysis. Notes were taken, through the full data set, about the various criteria used to evaluate projects, as well as stories about decisions, the explanation of screening techniques and the decision questions asked to help make decisions. These notes were used to develop an initial codebook. A codebook is a set of codes, definitions and examples used as a guide to help analyzing the data, and providing a formalization of the codes [250]. The goal of this first round of data analysis is to get familiar with the data; identify the codebook and to build systematic examination. At this point the initial codebook contained 36 concepts and served as the basis for coding the interview transcripts.

During the second phase, researcher code all the transcripts word by word to abstract information about the nature of the FFE project evaluation, criteria that have been used in screening projects, and the process or behavior applied in making decision. New codes were added when there was indication that the codes had not capture some features. Each coding node represents a meaningful statement abstracted from the transcript. Coding was a lengthy process, each interview requires 7 to 10 hours of coding. Generating these codes was one of the most challenging tasks in the analysis, since they could not simply be determined; code generation required understanding of human behavior as well as nature of the fuzzy front end. As new aspects became apparent, resulting in a codebook with 52 concepts. QSR NVivo 9 was used to conduct coding, managing and analyzing the large volume of data generated for this study. After the first coding round, the researcher identified reoccurring topics across all cases, which lead to further refinement of the codebook. The final codebook contained 42 codes. Excerpts from the codebook are provided in Table 5.3 (also see Appendix E). All transcripts were re-coded to this final codebook by the researcher.

To demonstrate effectiveness in classifying criteria or indicators used in the evaluation process, criteria have been defined using definition used in the literature to look up these criteria; in addition, one professor and two PhD candidates confirmed their agreement with the definitions.

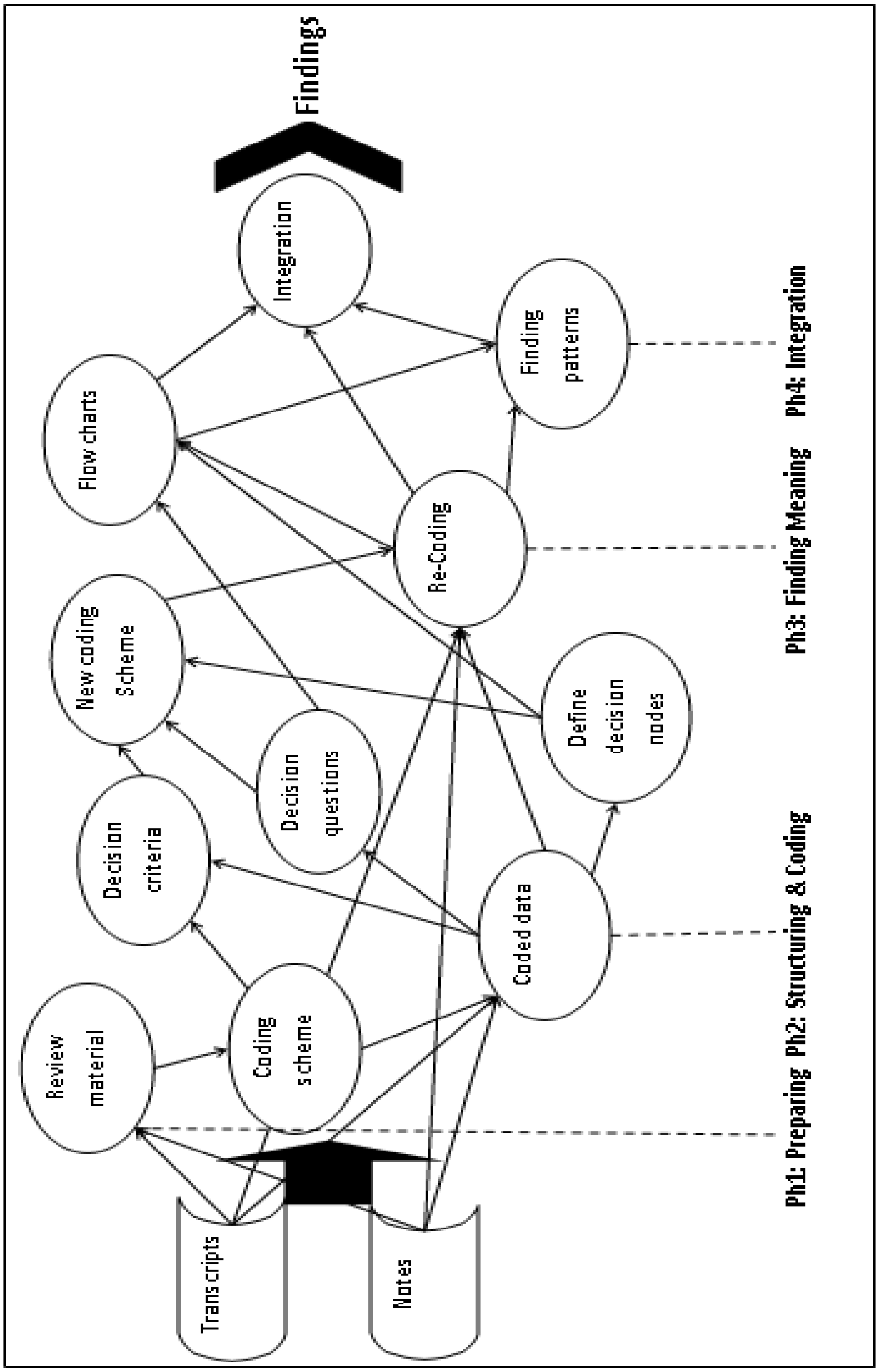


Figure 5.2 Phases of Data Analysis

Table 5.3 Excerpts from the Codebook

Class	Coding Node	Description	Look up Words	Example	Frequency	Note
Criteria	Product Concept	How good and coherent is the product concept? Does it appear desirable?	Solid idea, good idea, good features, it's different	Why my product is different?	53	
	Technical Feasibility	Are the production technology and skills available?	Feasible, know how to do it, can do it	Have the technology or at least have the knowledge to make it	63	
Decision Behavior	Experience	Compare to cases from previous experience	Experience, I saw it before, I learned this	From my previous experience. I did not trust this idea	26	
Decision Heuristics	Heuristic-EBA	Eliminate the project because of one or multiple reasons		Even though it was a good idea, it doesn't fit with what we are looking for	14	

In the case of the present research, a transformation from meaningful statements into coding node has been used, rather than propositions, to apply functionally-appropriate level of analysis [178]. Each code node would be a piece to understand the decision behavior and identify the heuristics approach in the later stages of the analysis. For example the following paragraph has been broken into six code nodes as shown in Table 5.4.

"It was technically going to take three years to have it ready and then we were going to get 15% of a market that we have not been in, but we never managed to finish it. I'm sorry; this is the dumbest thing I've ever heard in my life. Unless it's the best idea, when you go into a market and you've got to deal with any existing competition, it takes you three years to get where you think you need to be."

Table 5.4 Example of Coding

Phrase	**Code**
"technically going to take three years"	Production Time
"going to get 15% of the market"	Market Opportunity
"market that we have not been in"	New Market
"Unless it's the best idea"	Product Concept
"deal with any existing competition"	Competitors

In the third phase researcher reviewed the codes regard the updated codebook and drew flow charts.

The following example shows a chart illustrated from a transcript (Figure 5.3)

"Now if I just (ranked) the three of those and you come in and you have a, ok return, but not very high risk or I'm much more likely to do that. And so the other one is there's the context of just what's my overall portfolio, right? I'm much more likely to grab your idea, right, because I'm going to be thinking, "I have three of them where I'm swinging for the fences, and when you try to hit a home run, a lot of times you strike out. So I got those. So you come in, you could get me on first base, it's a solid business, it's not going to be high risk, it's not going to change the world, but we're going to make some money on it. I may be able to build off that franchise, I may not be able to. Well then, I'm probably going to do it. Now, if I haven't done any home runs and you come in with this home run idea."

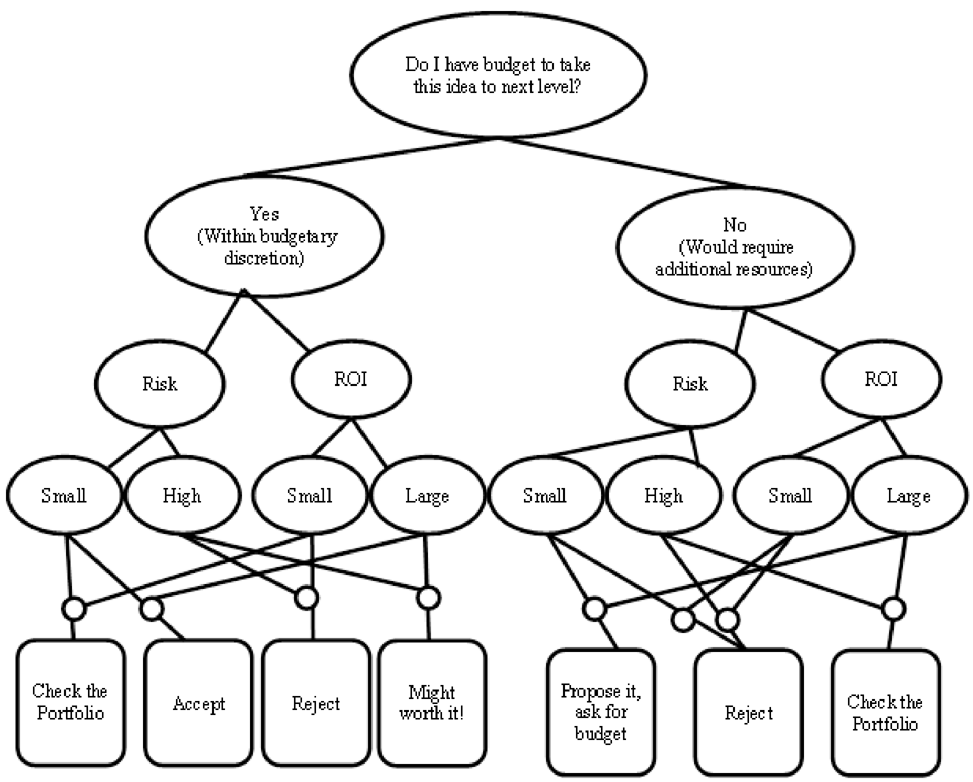


Figure 5.3 Chart Illustrated Form an Interview Transcript

A progressive literature search was conducted in parallel with data analysis to serve as another source of quality assurance. Cases in hand were tested against different heuristics' definition and examples in the literature to identify the right heuristic. New heuristic been identified and all data been re-coded against these heuristic to ensure the sustainability and enhance accuracy. Later in the analysis; phase 4, essential categories and well known decision heuristics were chosen to serve as a vehicle for integration and improvement. Coding and descriptive flowcharts and diagrams were then used to build the model.

Research analysis identified 66 decision cases, gathered form twelve interviews. The end product of selection coding was a dataset of 22 decision criteria, list of decision questions and four decision heuristics.

To ensure reliability, as suggested by research [178, 248], all steps of the research were carefully documented, all interviews have been transcripts, codebook have been clearly described and kept up to date and reviewed regularly.

The structure and analyzing approach were clearly defined. Two interviews (one from each round) were independently coded by a second researcher to check for inter-coder reliability, as suggested by researches [214, 221, 234]. Results on inter-coder reliability show codification agreement of 85%. In addition, two PhD candidates have been asked to code random pieces of the interviews. The matching results of 86% confirm the validity correlation between coding.

5.5 **Summary**

Two of the knowledge elicitation techniques were applied to collect data. A total 66 decision cases were collected from interviewing twelve respondents from companies with active R&D pipelines, and from the Innovation Program Council. Four proficiency scale methods were applied to choose these expert respondents. Data analysis was done using QSR NVivo 9, the qualitative data analysis package, and took place in four overlapped phases: preparing data, structuring and coding, finding meaning, and integrating a codebook was developed collaboratively through several rounds of going through the interview reports, the interview guide, and the original research proposal. Data analysis process focused on identifying information about the nature, context and process of front end project evaluation, criteria used in project screening, and the sequence and structure of decision points. The goal of the painstaking analysis process is to abstract information about the nature of the FFE project evaluation (serve answering RQ1), criteria have been used in screening projects (serve answering RQ2), and the process or behavior applied in making decision (serve answering RQ3). The results of data analysis process are discussed in the Chapter 6.

CHAPTER 6: RESEARCH RESULTS

The results of this study answer three research questions: what are the main objectives and constrains for FFE project screening? What are the criteria used in the evaluation process and how are they integrated and used to discern alternatives? Are similar heuristics used by different decision makers? These questions are answered by identifying the context of the heuristics (section 6.1), the structure of heuristics (section 6.2), types of heuristics identified (section6.3) and then integrating the results into a decision model (section 6.4 and 6.5).

6.1 Context of Heuristics

The research analysis shows that the fuzzy front end of project screening is, indeed, fuzzy; there is no standard path through the front end and none of the decision makers use a structured decision approach. Ideas are evaluated individually as they come in; there is no evidence that decision makers compare multiple project ideas against each other and select ideas that they fund. The only comparison mentioned by respondents is a comparison of ideas against projects that already exist in the project portfolio – if an idea is a long term investment and there are already many other long term investment in the portfolio it may be rejected because of this.

No centralized documentation of early stage product idea exists. Managers can recall individual projects, but they are unable to recount their complete story from initial idea through informal and ad-hoc screening stages, to formal project evaluation, development, and product launch because the managers' responsibilities and involvement with the project change through the lifecycle of the project. Despite this lack of feedback-learning opportunities, managers compare current project proposals with past projects or previous experiences to identify patterns of success and failure. This occurs in an ad-hoc and somewhat intuitive manner: 10 out of 12 respondents in the study mentioned that they rely on their own personal experience, which has been mentioned in the discussion 25 times. As an example, one of the respondents (R12) said:

"You know, it was a really very creative idea in fact so creative that nobody has done anything like it, and you know nobody had done this idea. It wasn't close enough to any existing work that I can even evaluate it."

Respondents furthermore mentioned gut feeling as a guiding inner voice in the evaluation process 45 times.

Overall, they characterize the decision processes as fluid, uncertain and characterized by a need to act fast. Screening decisions at this stage are based on fast and preliminarily evaluations of projects. One of the respondents (R5) describes the needed decision at this stage to be:

"Fast in time to no (N-O) or know (K-N-O-W). We wanted to get to 'K-N-O-W' if we should move forward or 'N-O', to reject it fast."

Initial screening decisions are made despite very high levels of uncertainty about customer preference, markets, competition, and general economic trends because decision makers feel gathering additional information will not dramatically reduce uncertainty, but might lead to delays that could cause the product to miss the market window. For example, responded (R3) mentioned:

”And so, I could have- at that point- taken two approaches, one is not commit, and then spend weeks and weeks collecting data in hope of showing that we can do something, but, it would have impacted a lot of the other work we do. So, I chose to take the risk.”

To manage uncertainty, some managers employ an exploratory strategy of allowing several projects to move forward with the knowledge that some will be discontinued later. For example (R3) said:

“Sometimes we’ll get after two ideas for quite some time until we have to make the commitment. And say, ok we need to go this way“

Respondents describe their decision processes as asking a series of questions about the project, such as “What are other products in the market that are close to this product?”, “Why is my product different?”, “Do I have the technology or sufficient knowledge about it?" or "How much market share do I expect?” All questions mentioned by the respondents pertain to their decision criteria, which are discussed in the next section.

6.2 **Structure of Heuristics**

Not surprisingly, the decision criteria differ from respondent to respondent. All respondents think about the detailed tasks and success factor for the particular project at hand and select criteria accordingly. Five respondents additionally approach project ideas from a portfolio perspective and ask how the product idea serves the company's business strategies; Appendix F shows the criteria used by each respondent.

The most frequently mentioned criterion that was mentioned by all respondents is technical feasibility (coded 63 times). It also seems to be the single most important criterion that respondents use to make early reject decisions: if they do not see how the project can potentially succeed technically, they reject it without further investigation. Other frequently mentioned criteria are: product concept (how solid and comprehensible is the idea to the decision maker), which has been mentioned in 52 codes, and customer need, mentioned 43 times (see Table 6.1).

For the most part, the research confirmed the decision criteria for project screening that are discussed in the literature and implemented in analytical screening tools. However, respondents also identified three criteria that the screening literature rarely mentions; creating a new norm (mentioned 21 times), personal interest or enthusiasm for the idea (mentioned 25 times), and credibility or reputation which include the reputation of the idea giver (mentioned 38 times), the impact it would have on decision makers' reputation if he were to promote the idea (mentioned 5 times) and the impact on the brand reputation (3 times). On average respondents mentioned 11.41 unique criteria (SD = 3.7) and thus substantially fewer than the criteria catalogues published in the literature that contain between 37-45 criteria [46, 60, 87, 134, 256]. Respondents in the process tracing group mentioned fewer unique criteria (mean = 8.67, SD = 2.49) than respondents in the CDM group (mean = 12.33, SD = 3.62), which is to be expected: while CDM reflects on cases embedded in several different decision situations, process tracing only capture one particular decision situation and the criteria used in this particular context. Differences in the number of unique criteria mentioned by the respondent hint at strong individual differences and are not likely to be an artifact of the interview protocol or interview length: in the CDM group respondent 1 was interviewed for 45 minutes and mentioned more unique criteria than any other respondent (21), whereas respondent 4 could only identify 11 criteria in 55 minutes, using the same interview protocol. Table 6.2 summarizes the criteria and the frequency with which they have been mentioned in the evaluation process. Appendix F presents the same information by respondent.

Table 6.1Criteria Used by Respondents for Project Screening

Criteria Identified Experts	Identified In Literature Yes	No	Frequency	Notes
Business Scope	X		14	
Company Portfolio	X		10	Not Identified in literature as screening criteria
Competitors	X		31	
Creating a New Norm / New Idea		X	21	
Credibility/Reputation Reputation of idea proposer Preserving ones Credibility Brand Reputation		X	 38 5 3	
Customer Needs	X		43	
Future state of the economy	X		3	Not Identified in literature as screening criteria
Funding	X		20	
Manufacturing Time and Process	X		8	
Market Opportunity / Growth	X		37	
New Market	X		4	

Criteria Identified Experts	Identified In Literature Yes	No	Frequency	Notes
Personal Interest or Enthusiasm		X	25	
Product Concept	X		52	
Profitability	X		23	
Resources	X		13	
Risk	X		19	
Size of Investment	X		11	
Technical Feasibility	X		63	
Technology Significance	X		15	

It is noteworthy that the respondents feel that some criteria are more important than others and only use the less important ones when they cannot reach a decision based on the important criteria. They do not evaluate criteria independently, but lump them together in groups of criteria because they suspect them to have an interdependent relationship, for example, high return always goes with high risk and R&D costs and should consequently be assessed together. They also feel that some criteria cannot be evaluated without consideration for other criteria, for example, they evaluate the expected R&D costs in comparison to size of the business opportunity.

6.3 Decision Heuristics

All respondents, other than respondent 3, use two or more heuristics. In total, four main heuristic approaches were identified: recognition, elimination (in two variations), conjunctive, and tallying heuristics. Appendix G represent which heuristics was used by each respondent. All four heuristics are described and modeled in the following section.

6.3.1 Recognition Heuristic

The recognition heuristic has been described in the literature as recognizing a plausible course of action as the first one to consider [103, 171] (See **Error! Reference ource not found.**).

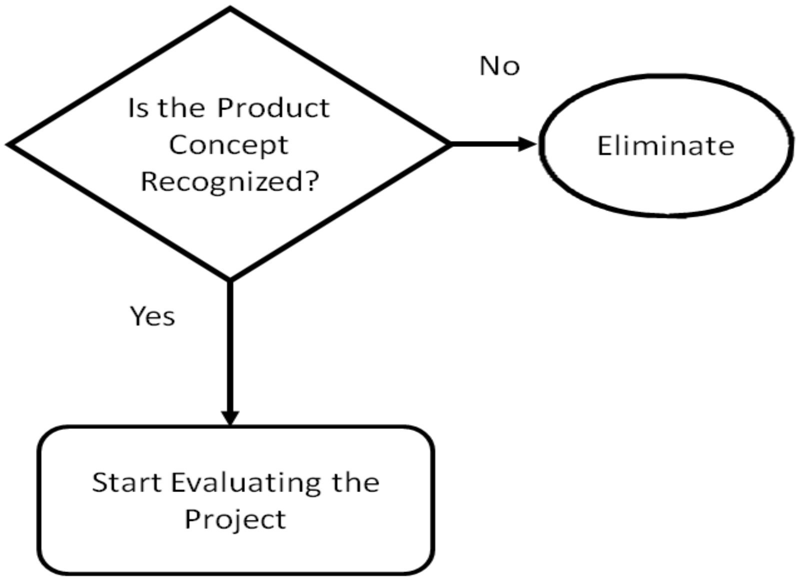


Figure 6.1 Recognition Heuristic Flowchart

In 16 cases respondents reported that they reject project when they do not see sufficient similarity of the product concept, the technology it requires, or the business context of the project and their experience – because they do not recognize enough familiar aspects, they reject the idea as out of scope. As an example, respondent R12 said:

"You know, it was a really very creative idea in fact so creative that nobody had done anything like it. It wasn't close enough to any existing work that I can even evaluate it."

This rejection typically stops any further evaluation. Only one respondent (R11), who is one of the innovation council members and therefore has easy access to other project screeners, mentioned the possibility that the rejected idea may find a sponsor after all:

"So, If I don't feel that I know enough about the proposal, I probably bring some outside help or else give it away to the committee who organize, just defer to the member who actually knows what is going on. So, I'll have some interesting questions to my colleagues on this first proposal, but my… off hand… is no… I would rather to see a different proposal"

No other respondent mentioned this possibility. Typically the unrecognized idea dies unless the proposer pitches it successfully to a different decision maker.

6.3.2 Elimination by Aspect

Once the decision is made to evaluate the project, most decision makers strive to weed out bad ideas very quickly, by applying a subset of criteria that are of particular importance to them. If a project does not reach a minimum level on the most important criteria, it will be rejected without consideration regardless of how well idea performs with regard to other criteria. Tversky explains this process as "At each stage in the process, an aspect is selected (with probability proportional to its weight), and all the alternatives that do not include the selected aspect are eliminated. The process continues until all alternatives but one is eliminated" [251] page 281. The flow charts that abstract this heuristic follow the structure of the flowchart shows in **Error! Reference source not ound.**, where it counts the negative values of criteria in a counter; if the decision maker has enough reason (N negative values for criteria) to eliminate this project, the project will be rejected; if not he will go through another evaluation afterward.

In the following quote, respondent (R7) explains that he eliminates projects with low return of investment:

"I look at the ones that are out there and rule out the ones that are economically prohibitive, some that I say, look, even if we can make it, it'll be so expensive that we can never do it profitably."

Similarly, another respondent (R10) talks about elimination based on technical feasibility:

"I think RFID has a very short active distance, like when we go into the door here, I take my wallet out and I have to push it up, almost to touch the door, right? So, to me, I think, it was a complete failure to understand the technical complexity"

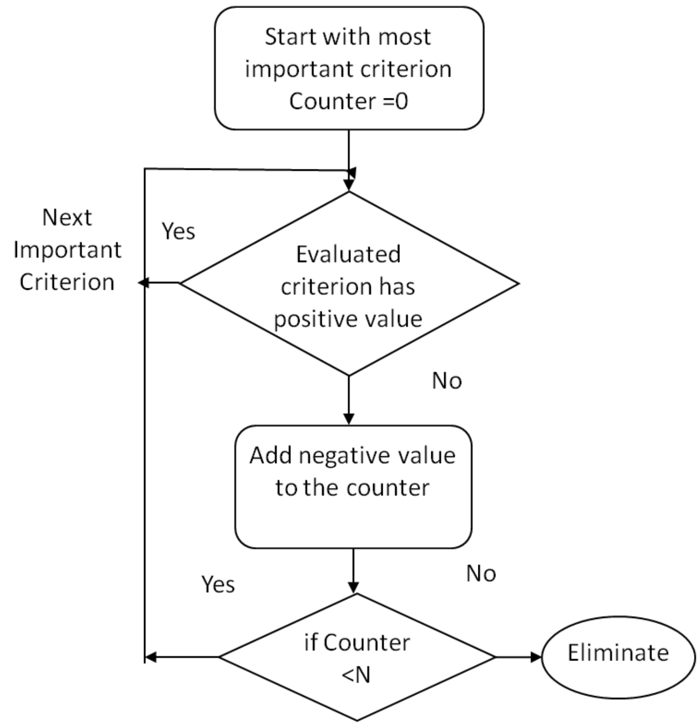


Figure 6.2 Elimination- by- Aspect Heuristic Flowchart

Another respondent (R4) refers to a rule of thumb used to eliminate projects:

"As a rule of thumb the revenue generated- probably in the third or fifth year- has to be at least 1% of the company's total revenue in order to be significant, less than that - they're going to say who cares, why I should put money in this, it is a waste of time. Unless there is a strategic reason: you say we got do this because if we do not do this our competitors... different story. "

Some decision makers attempt to assign a project to mental categories, a process known in the literature as Categorization-by-Elimination (CBE). CBE "uses only as many of the available cues or features as are necessary to first make a specific categorization, and eliminate those who do not fit with any category" [89] page 54. Categories are based on the respondent's mental category for projects of the type 'accepted' and projects of the type 'rejected'. Each category is based on different criteria. The project has to achieve a minimum level for each criterion in a category to be assigned to the category.

Categorization heuristics have been observed mostly through thinking aloud procedure (see Appendix G). The following quote was taken while the respondent (R12) was screening proposals and stacking them into different piles: the 'go pile', 'may be yes pile', 'may be no pile', and the 'no go pile':

"So, there are probably four proposals in here out of the nineteen where you just say "yeah, yeah, yeah"….there is these for "partly okay"-. This one is probably in the no-ish pile; this one is probably in the no-ish pile, [respondent looks at a third paper]… probably no-ish pile"

6.3.3 **Conjunctive Heuristic**

The conjunctive heuristic is based on satisfaction levels [250]. A project idea that did not get rejected in an initial cut is checked against a list of 'must-haves.' Once the decision maker reaches a level of satisfaction, he makes an acceptance decision (See Figure 6.3). The conjunctive heuristic was first observed in consumer choice by Hauser [250] and also becomes apparent in the study, as the following example highlights where the respondent (R9) clearly said:

"If you see it is promising enough, you should take the risk."

Sometimes the decision depends on satisfaction with the project based on one important criterion, such as confidence in the idea, enthusiasm for the project, or – as in the case below – the potential for consensus among decision makers that will be involved later:

"We don't have a formal process for that, my vote is worth so much... Ultimately, at the end of the day, I think if I can't reach a consensus its likely going to probably be "no". We have to really be able to reach alignment on whether this makes sense or not, and if I can't then it's probably no."

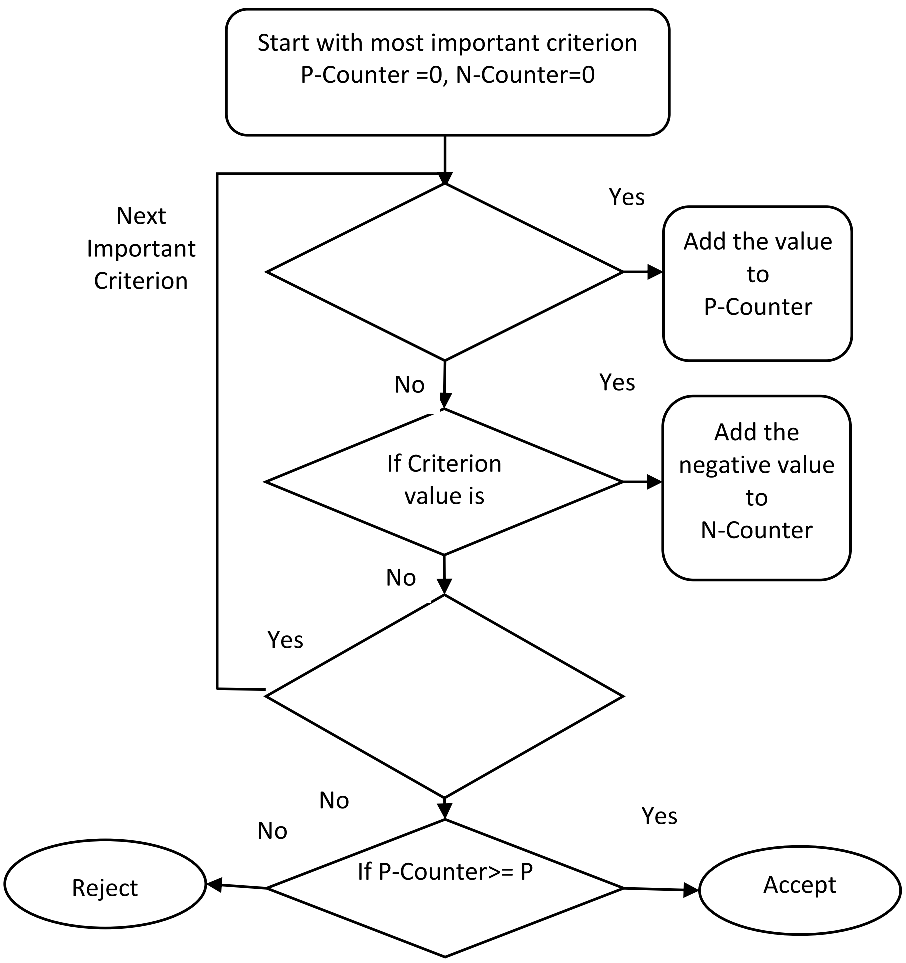


Figure 6.3 Conjunctive Heuristic Flowchart

6.3.4 Tallying

Some decision makers seem to weigh the pros and cons of the project. To do so they look at all criteria on the same level of importance and compare the number of criteria in favor of accepting (pros) against the number of criteria in favor of rejecting (cons). If they are even, they move to the next level of importance and repeat the process for all criteria on that level, until a decision can be made. This level-wise tallying heuristic is an advanced form of tallying [114, 168]. It considers arguments on the same level of importance. Interdependent criteria are included on the same level. The heuristic computes the score by adding up the number of pros and then subtracting the number of its cons (on the same level). As respondents (R1) mentioned:

"In general we approach it as: let's expose it - by the way of the pros and cons."

A project is chosen if its net score meets the predefined minimum expectation level of the decision maker (See Figure 6.4), as the following quote from respondent R8 shows: he weighs all arguments in favor of the project against his concerns before he reaches a decision:

"Ok, a product has been proposed to make a new piece of technology (I don't want to go through the details), the product concept was good, it sounds solid and it is achievable, we can make it. The proposer thought that we have the ability to market it through the same channels we market our current products, we just need to advertise for

it as we advertise for any new products, and he showed me some estimation for a good return of investment... it sounded good, but I struggled for a while because this investment is not within our core business, we are not familiar with this market."

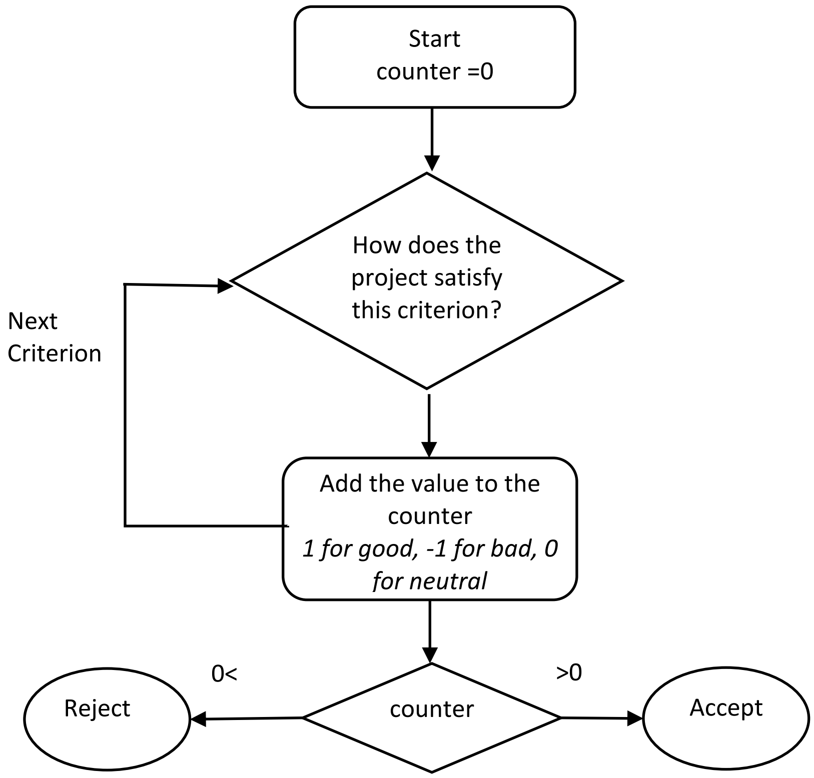


Figure 6.4 Tallying Heuristic Flowchart

6.4 Integration of Results

In this research individual managers show that project screening does not occur through a single screening heuristic, but through a sequence of heuristics that vary between respondents and situations. Table 6.2 shows the times each of these heuristics presented in the cases. The same information, organized by respondent, is included in Appendix G.

Table 6.2 Heuristics Presented in the Cases

Heuristics	Definition	Number of Cases	Number of Respondents
Heuristic-Recognition	Make a decision depending on recognizing or not recognizing the idea by the decision maker	16	8
Heuristic-EBA	Eliminate the project because of a certain or multiple reasons	16	8
Heuristic-Categorization	Categorize this project under certain group or class	7	3
Heuristic-Conjunctive	Reach a level of satisfaction to make a decision	10	6
Heuristic- Tallying	Evaluate pros and cons of the project	10	7

A commonality of the observed screening approaches is an initial focus on recognition and elimination-by-aspect. With the exception of respondent 3, who only pointed out one heuristic (Tallying), each respondent is either using recognition (3 respondents), or EBA (3 respondents) or both in sequence (5 respondent). Both heuristics rely on a very small number of criteria or a single reason that lead to rejection. Respondent (R6) clarify this order when he said:

"So, I think, the first factor in deciding. If it is a great idea for us, is this kind of product or brand that we understand? Is it something that we deeply understand? And understand its customer? So, that's a big one for us. If we say no to that; if it's not something that we have that level of understanding, we're probably not going to take a look at it. So the first consideration for us is that"

Ideas have to overcome the initial elimination steps in order to be evaluated more thoroughly, based on one of the three heuristics of categorization, conjunctive, or tallying heuristics, or a combination thereof. These heuristics use more criteria than the initial steps, but by no means the 37 and more criteria that are described in the literature as part of decision aids.

Overall the study thus confirmed that managers ignore some information and use fast approaches to reach a 'good enough' solution that 'satisfices', rather than seeking and optimal solution: as can be seen in Appendix G, all respondents (but respondent 3) have at least one very simple heuristic, based on few criteria, and one more complex heuristic that takes more criteria into account in their repertoire. Furthermore, there is evidence that they adapt their heuristic strategy to the situation, if one set of criteria and one particular heuristic does not lead to conclusive results, additional criteria and heuristic approaches are added. In that sense, managerial screening heuristics are ecologically rational [89]. For example respondent R9 chose different criteria to eliminate project ideas; in the first decision case he relied on 2 criteria, namely technical feasibility and financial return, *"I don't want to go after a new idea until I'm sure I can do it both financially and technically."*

While in a second decision case he rejected an idea because it was out of the business scope:

"Even with that, we choose not to invest in it because it is out of the company scope; it is not what we have been doing and it might takes the company into a different direction"

A general integration model that shows a logical sequence of the decision heuristics process is depicted in Figure 6.2.

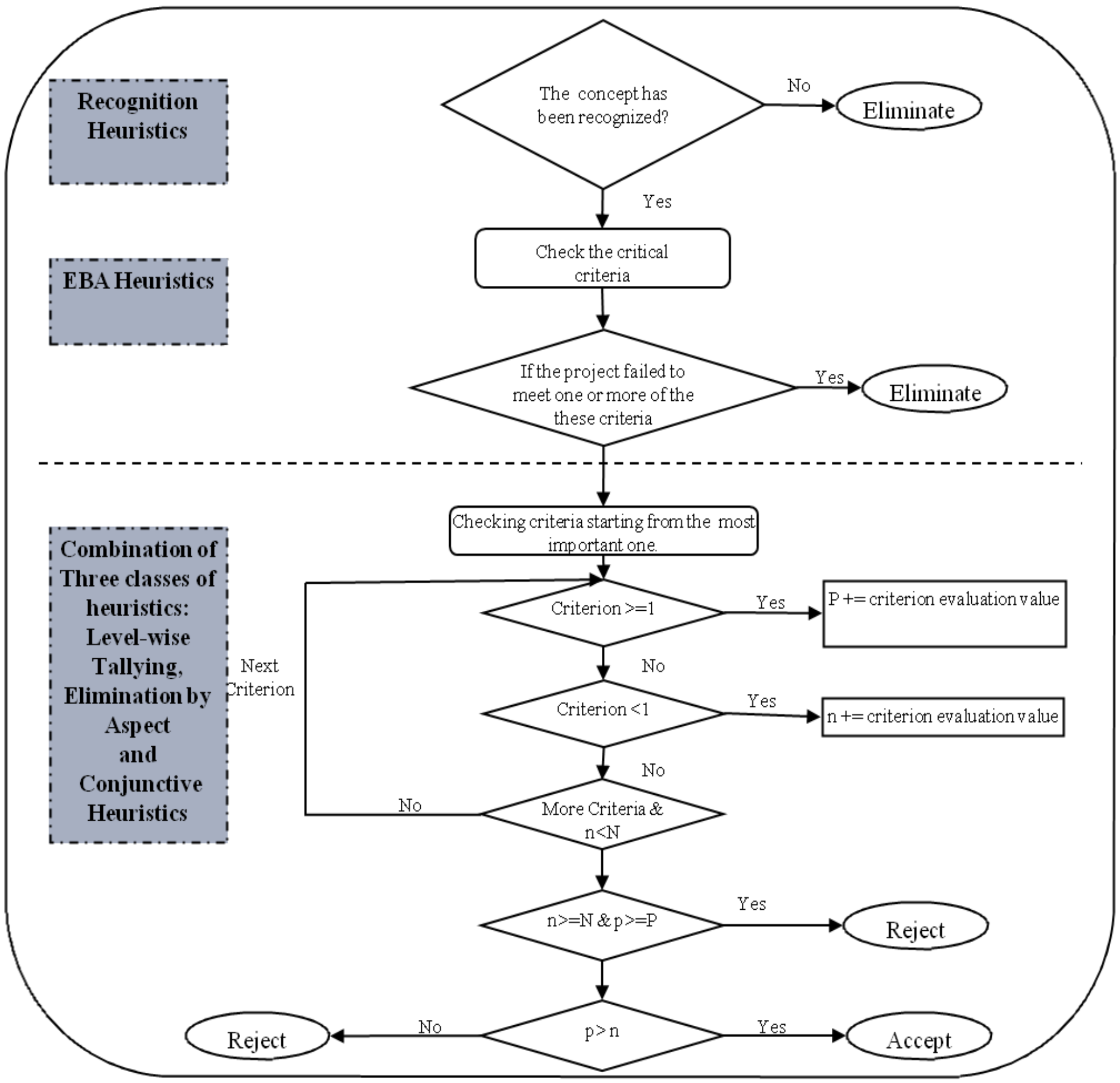


Figure 6.5 Heuristic Decision Model for Screening Product Ideas at the FFE

Where:

N is a constant variable represent the maximum number of negative criteria

P is a constant variable represent the minimum number of positive criteria

<u>Tallying</u>

N= Total number of criteria, and P= 0

<u>Elimination by Aspect</u>

N < half of number of criteria, and P= 0

<u>Conjunctive</u>

N < half number of criteria, and P = minimum number of positive criteria need to be approved

This integrated model does not show the decision process of any particular decision maker, but highlights at which stage in the screening process the different screening heuristics are likely to be used. Individual differences may exist. It is furthermore noteworthy that the thinking aloud procedure elicited more different decision heuristics per respondent (mean= 4.33, SD= 0.577) than the CDM (mean= 2.11, SD= 0.6009) (see Appendix G), which points at the difficulty of respondents to recollect past screening processes in full. However, each heuristic described above was identified by both elicitation methods at least once. It is therefore unlikely that they are an artifact of the interview process.

6.5 **Unassigned heuristics**

This study identified 66 decision cases – in 59 of these cases the respondents' decision heuristic for the particular case was identifiable and could be matched to one of five fast and frugal strategies above. In 7 cases, the respondents' particular decision strategy could not be clearly identified.

In some cases this was the result of the respondent's inability to remember all information related to the decision making. For example, one respondent (R8) described a process of weighing pros and cons for a project, which may point at a tallying strategy, but could not provide sufficient detail:

"In the past, the company developed and produced a video camera, it was a big mistake... yes we had the ability (in term of resources, technology, etc.) but it is not our core business... We designed a somewhat a nice video camera, with some unique features

(I don't remember exactly what were the features, but it supposed to do something cool at that time.) It was completely a new market for us, with tough competitors. So, we couldn't compete in this high competitive market where some good brands are already there (you know, Sony, Samsung, Toshiba, Canon,…), the estimated market share we had was already small and we did not even get it."

In other cases respondents described decisions incompletely and in very general terms, despite the interviewer's effort to get respondents to talk about specifics. One such example is respondent R4, who recalls a decision process with a negative outcome that he blames on unspecified internal politics – the many omissions and incomplete sentences hint at the fact that the respondent was distraught thinking about past events:

"*Well it was bringing a kind of new technology, I mean.... a company basically drills holes in tiny, tiny holes in various electronic circuit using lasers, and this was a new way of manipulating to give optimal drawing characteristics. The company was highly political and if certain people did not think it is going to work, they would intend to fight you. We proposed it anyway and we went forwarding with it, damn it did not work."*

Another respondent (R4) tried to generalize the process instead of giving information about a specific project:

"The judgment made relative to the maturity of the staging of the technology as well as the size and importance of the market opportunity"

"You have one project that has high risk and if it succeeds you will get good present for your business (revenue, market share, branding…), and another project that has, maybe, not high risk but also may not give us the best results (low revenue). In our case, we recognize that sometimes you have to take a risk and your portfolio should contain a bunch of high risk high payoff, medium risk maybe medium to low payoff, and then sure things you got to do and you got to get into production"

The latter statement hints at the possible use a priority heuristic [94] that first assesses what could be gained/lost in the worst case and if this does not suffice to make a decision, further evaluates how probable it is that these gains or losses occur and what the best positive outcome would be. However, as in the case with the general statement about decision criteria, the respondent comments are not specific enough to draw conclusions. It was therefore impossible to match all decision cases in this study to a decision heuristic.

CHAPTER 7: DISCUSSION, LIMITATIONS AND FUTURE RESEARCH

7.1 Discussion

This research is one of the first to open the black box of managerial intuition by investigating decision makers' screening heuristics in the fuzzy front end through cognitive task analysis. Not unexpectedly, it confirms that decision makers who are faced with very limited information, lack of time, and scarce resources use mental shortcuts to quickly reach a decision to promote a product idea or to reject it. The decision makers, who serve as gatekeepers [5, 37, 239] for new ideas make their initial screening decision individually, in an unstructured environment, with no involvement of other decision makers and without any documentation of proposed ideas and decisions. They furthermore do not typically see the proposed and approved projects through to their final outcome, which may occur years later and after major modifications to the initial idea. As a result, decision makers face a situation that is less than ideal for feedback learning, yet they rely on their cumulated experience to determine what criteria to apply and which heuristic to pull from their repertoire of decision strategies. Depending on an individual's past learning opportunities and experiences they may reach different decisions, even if presented with the identical project in the identical situation.

The heuristics of the decision makers in this study have all been described in other contexts before - not surprisingly, early stage project screening does not follow fundamentally different cognitive strategies than other decisions. Decisions follow a satisficing strategy and are based on few criteria that are sufficient for a "good enough" solution. However, the respondents do not use the most simplistic (e.g., lexicographic) fast and frugal strategies. They furthermore face decision problems that seem to frequently require a combination of several F&F decision strategies, as the integration model in Figure 6.5 demonstrates: early on in the decision process, ideas have to be not rejected to survive - decision makers use recognition and elimination-by-aspect, based on one (recognition) or very few (elimination-by-aspect) criteria as their key strategies. Once an idea has made is past this hurdle, other, less decisive criteria are evaluated and pros and cons are weighted. With the exception of respondent 3, each respondent has at least one early and one later-stage decision heuristic in his repertoire (see Appendix G). Respondents thus use 'fast and frugal' strategies but in a complex combination, which highlights the ongoing discussion about the applicability of fast and frugal heuristics as plausible models of cognition [252, 253].

The decision maker's focus on ecological rationality and single (or few) reason decision making may furthermore make it challenging for them to apply many of the multi-criteria decision tools recommended for later stage project screening, such as Analytic Hierarchy Process (AHP) [50] and scoring models [27]. Moreover, these approaches require that criteria are treated independently, while respondents in this survey clearly lump criteria together. This may contribute to the lack of usage of these tools in practice [22, 37].

This study sheds some light on the individual differences that exist with regard to the criteria (see Appendix F) and heuristics (see Appendix G) despite their comparable backgrounds and, in some cases also positions, respondents differ considerably, and even the same respondent (e.g. R9 mentioned above) use different criteria and heuristics in different decision cases:

A total of 23 screening criteria were identified in this study. Across all respondents the study thus found substantially fewer criteria than the criteria catalogues described in the literature, but also identified several additional criteria that were focused on personal interests and reputation. Two criteria, namely technical feasibility and competition, were mentioned by all respondents. Technical feasibility was furthermore the most frequently mentioned criterion and referred to 63 times. Other very frequently mentioned criteria are the solidity and clarity of the product concept (52 references) and customer needs (43 references), yet product concept was not mentioned by 3, and customer needs were not mentioned by 2 respondents. Moreover, 10 criteria were mentioned by less than half (≤ 5) respondents - among them generally accepted screening criteria like manufacturability and growth of the potential market. Overall, respondents thus operate with a relatively short list of decision criteria (average 11.41), from which they select a subset for each decision case. Their choice of criteria in each decision case is subjective and may be a suitable adaptation to their specific work environment - for example, manufacturability may pose little challenges for equipment manufacturers who assemble few product units with highly flexible production equipment. It may, however, also introduce problematic 'blind spots', such as passion for technology with little regard for true customer needs. However, as long as these potentially problematic screening decisions are caught at a later stage, but still relative early in the product development process, they are likely to have only minor impacts.

A more severe problem may arise if the criteria and screening heuristics used by individuals systematically discourage potentially valuable ideas: the strong focus on recognition as a heuristic (8 out of 12 respondents) may pose a problem because any idea that does not look sufficiently similar to past experiences is rejected. Furthermore, several of the frequently mentioned criteria have an element of decision makers wanting to stay in their comfort zone: they all emphasize technical feasibility (which at the early stage the projects are evaluated in is a judgment call) and mention their own interests and enthusiasm, as well as the need to preserve their credibility as relevant for their decision. These decision practices may make it difficult to find sponsors for truly innovative, out-of-the-box ideas and may lead to a systematic initiation gap for radical innovations, which has been observed by [13]

7.2 **Limitation**

By employing two complementary data collection approaches to research the screening behavior of 12 experienced decision makers, this study was able to open the black box of the early stages of new product development. However, some limitations exist.

The study was unable to observe heuristic project screening in real-time in its real-world setting. Such observations would require the researcher to shadow decision makers for extended periods of time and to do ad-hoc process-tracing study, based on thinking aloud protocols, whenever an idea is proposed and evaluated - clearly an impracticable research design. This study therefore combined CDM and process tracing concurrently: CDM was able to investigate decision contexts and uncovered the range and variability of decision criteria, while process tracing was particularly successful in uncovering decision heuristics.

The study is unable to explain the differences between decision makers, which would require both deeper insights into their current work environment and a full understanding of how the respondents have acquired their heuristic knowledge. This limitation should be addressed in future studies.

7.3 Implications and Future Research

This research provides several opportunities for improving management practices and for pursuing further research.

This research has observed differences in the criteria and heuristics managers employ to screen projects, and demonstrated their variability across different decision points. It is currently unclear to what extent these variations are reflection of individual decision making styles and to what extent they are adaptations to the particular decision situation at hand. Deeper insights into these issues will make it possible to understand what makes reportedly successful gatekeepers more successful than others: do they have better heuristic strategies in their toolbox or are they better at choosing from their toolbox the heuristic that is most appropriate for the situation? This understanding can potentially lessen a managerial bottleneck in the fuzzy front end since it is difficult and time-consuming to accumulate screening expertise, experienced gatekeepers are scarce and product ideas often 'linger around' in the front end for extended periods of time [29]. In addition, there may be individual differences in the way people apply different heuristic or choose more analytical processes over heuristics. If these differences could be established and validated, it might help assign individuals to conditions where analytical evaluations are necessary versus those where analytical evaluations are not possible.

By providing one of the first formal models of a decision maker's screening behavior, the study provides both a research and a potential training tool. As a research tool it enables research to investigate the quality, accuracy and overall effectiveness of heuristic project screening approaches and compare them to fully rational models, rather than assuming that heuristics are systematically inferior. This will shift the focus of project screening research from the identification of screening criteria, the majority of which are not considered in the early screening process, to the heuristic strategies with which they are evaluated, providing a much needed addition to the state-of-the-art tools currently available. Prior research [132] shows that the same criteria, evaluated with different heuristic approaches, can lead to very different project selection decisions. Moreover, the model will help to understand systematic biases in decision makers' screening strategies: Which strategies lead to more or less project rejections? Which one is better at picking winners? Does the recognition heuristic at the beginning of the screening process lead to a systematic initiation gap for radical innovations as observed by Colarelli O'Connor et.al [13]? And does this have a lasting impact on the level of innovation throughout the front end pipeline or are there always enough good ideas that take the place of a wrongfully rejected idea, as [29] states?

The models resulting from this study could potentially also serve as decision support approaches and training programs that communicate the strategies of successful decision makers to their less experienced peers. This could provide great benefits by overcoming the bottleneck of experienced front end screeners and improving decision outcomes, as the use of simple decision-aids in medical decision making demonstrate [104], where it may be more efficient for training programs to be re-conceptualized to emphasize the perceptual learning needed to make fine discriminations and the array of experiences needed to develop situational awareness skills. This question is of particular importance because the fuzzy front end is a less than ideal learning environment for experiential learning and screening expertise therefore only builds up very slowly (or not at all), unless some support is provided. Further research will clarify if this is best achieved by codifying and transferring successful heuristics, by using a simulation-based learning environment that provides feedback and thus allows managers to develop adequate and individual heuristics much more quickly than real world experiences [44], or a combination thereof.

While many of these potential applications of these research findings still require future research, this study also provides some short-term managerial implications. Companies need to understand and appreciate that decision makers heavily rely on heuristics for screening innovative ideas and should attempt to put the best possible heuristics to work. This suggests that decision makers need experience that allows them to quickly recognize the most important criteria to evaluate, and to recognize the dynamics of the project and the market to be able to make judgment according to these criteria. This requires opportunities for feedback learning by communicating decisions, criteria, and outcomes to initial screeners, even if they are not involved in the project anymore. Moreover, if the screeners' tendency to reject what seems too different is a concern, companies may want to think about ways to increase the diversity and size of the pool of gatekeepers, for example through idea contests, or by setting aside resources that proposers of ideas can use to mature them further without the need for approval, such as Google's and 3M’s policy to allow for time for personal projects.

Finally, the results suggest that it would be a mistake to develop decision aids along the lines of only decision analytical theories, such as Analytic Hierarchy Process (AHP) [50] and scoring models [27]. In the FFE, with its high of uncertainty, people will not be able to perform the operations needed to make comparative judgments and will always rely on heuristic. Only some of these heuristics are compensatory and none of them weigh criteria. Furthermore decision makers treat criteria as interdependent and cannot evaluate alternatives criterion-by-criterion, but frequently link criteria them evaluate them together. These insights may provide some strategies for improving decision aids, such as checklists and scoring models: overall, they may be more useful if they employed a less-is-more approach, focus on only few criteria, and do not dominantly aim at discerning alternatives, but by providing effective situational awareness.

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APPENDIX A- TAXONOMY OF RESEARCH ON HEURISTICS DECISION

Classification	**Research Topic**	**Reference**
Theoretical reviews, and in comparison with other decision models	Literature and theoretical review of human judgment and fast and frugal heuristics to show that human judgment is adaptive to time and cost constraints	[91, 100, 103, 138, 148, 151, 155, 165, 234, 254-264]
Usage of simple heuristics	Investigates the question if people make decisions in a fast and frugal manner? How often they use them? And how useful these heuristics?	[103, 119, 158, 161, 260, 265, 266]
Evidence of usefulness of using less information	Testing the confidence and accuracy of decision made with more information in comparison to those with less information. Key finding: less information can give same or better quality predictions	[95, 97, 110, 123, 258, 266-268]
Fast and frugal heuristics in use – medical field	Quality of fast and frugal decision tree in assisting physicians in diagnosing and assessing physician making quick decisions. Key findings: FF heuristics are more accurate than physicians' decisions and regression models. They have higher sensitivity and	[63, 104, 107, 164, 193, 196-198, 269, 270]

	smaller false rates.	
Fast and frugal heuristics in use – Forecasting	Comparing FF heuristics with different forecasting methods like regression model, artificial neural network, neighbor analysis, and intelligence analysis, for forecasting performance in sport, business and alarm, and others. Key findings: FF model give similar or close accuracy results in a shorter time	[63-66, 84, 85, 101, 106, 107, 112, 113, 132, 162, 193, 258, 270-272]
Researching different fast and frugal heuristics	Priority heuristics: algorithm, application and quality.	[94, 164]
	Categorization by Elimination and Elimination by Aspect heuristics	[63, 93, 108, 123, 165-167, 251, 271, 273-276]
	Take the best: algorithm, application and quality	[89, 92, 93, 98, 99, 107, 114, 132, 155]
	Tallying Heuristics	[89, 102, 132, 168]
	Conjunctive Heuristics	[113, 250, 277]
	Recognition Heuristics	[103, 114, 155, 278]

APPENDIX B- CRITICAL TASK ANALYSIS CASES RESEARCH TAXONOMY

Method	Research Objective	Results	Domain Experts – Sample Size	Reference
Thinking aloud	Choice of loan candidates	People use more information When there are similar alternatives.	11 loan officers	[279]
Thinking aloud	Choice of patient treatment plan	Those who used "typical" information produced better plans.	15 mental health professionals	[280]
CDM	Eliciting knowledge from expert neonatal intensive care unit (NICU) nurses	Information extracted from CDM used to form a guide to early sepsis assessment in the NICU, which contains information not available in the current literature	5 nurses	[198]
Coded verbal Statements	Choice of vender	Elimination by aspect has been used: Buyers first eliminated vendors on basis of price differences and delivery time and then looked at delivery history.	14 industrial buyers	[281]

		Number of alternatives had no effect on strategy used.		
Compared process tracing with regression models	Rating of maladjustment	Found evidence for linear and nonlinear strategies being used in rating task. Regression and process tracing had similar predictive ability and should complement each other.	1 student	[212]
Interview (CDM) and Observation	Assess the usefulness of CTA as an analytical tool in order that physician cognitive tasks may be understood and redistributed within the work-hour limited medical decision making teams	Five broad categories of cognitive activities were identified: pattern recognition; uncertainty management; strategic vs. tactical thinking; team coordination and maintenance of common ground; and creation and transfer of earning through stories.	14 members of these medical teams served at the ICU	[194]
Coded	Choice of	Number of verbal	20 students	[282]

Verbal Statements	candidates	statements did not differ across conditions but number of evaluative statements were related to type of display; display and verbal statement also related to search sequence		
Interview, Observation, and Workspace Analysis (Photographic Survey, Detailed Workspace Mapping)	Elicit expert knowledge about factor effect weather in the Gulf Coast	Develop concept map for weather forecasting that lays out expert knowledge about the role of cold fronts in the Gulf Coast	22 Participants; senior civilian forecasters, junior & senior Aerographers Advanced Journeymen and Journeymen who were qualified as Forecaster	[187]
CDM	develop a foundation of Knowledge	Identify parts of the job that require skilled judgment and evaluation.	10 participants each with	[236]

	regarding the Intelligence Analysts' task domain.		10 years of experience	
	Choice of car	Mood state affected response. EBA been used No subject used a linear strategy.	22 students	[283]
Coded Verbal	Choice of Apartments	Number of alternatives affected the evaluation. Non-compensatory strategies that concentration on fewer attributes.	9 students	[284]
CDM	The objective of this study was to examine the way in which decisions are made by highly proficient firefighter, under conditions of extreme time	A recognition-primed decision (RPD) model was synthesized from these data, which emphasized the use of recognition rather than calculation or analysis for rapid decision making	26 officers from 7 organization	[181]

	pressure, and in environments where the consequences of the decisions could affect lives and property.			
Interview & Observation	Describing Internal technology transfer and the implementation of technical innovations.		10 technical innovators	[285]
Field Observation & Interviews	Analyze the nature of nurses' cognitive work and how environmental factors create disruptions that pose risks for medical errors.	A high number of cognitive shifts and interruptions that disrupting nurse's attention during care of patients	7 staff registered nurses	[196]

Interview	Choice of groceries	Number of alternatives affected search sequence.	19 housewives	[286]
Self-report, Observation with Time Tracking	Compare the efficiency of using two methods of nursing documentatio n	E-Record improve the quality of documentation even though it has more steps	2 nurses	[197]
Coded Verbal	Choice of homes	Value of cues affected use of decision rules	6 students & home buyers	[287]
Interview, Analyzing the Cognitive Elements of the Task	Test the quality of training intern surgeons using knowledge elicited using CTA	Interns who studied cognitive process information have better performance than those who learn using traditional methods.	2 surgeons, experts in central venous catheterizat ion (CVC)	[192]

APPENDIX C- INTERVIEW GUIDELINE TEMPLATE

Name of the interviewee ……………………………………….

Name of the company ………………………………………..…..

Functional Role …………………………………………………..….

Years on Job ……………………………………………………….….

Years with Company ……………………………………………..…

Introduction:

At the first evaluation of new product concept, what is been called front–end, product opportunities are screened to identify those ideas that are promising and should be developed further into product concepts. This research aim to study the procedures and criteria used to evaluate project concept at this stage.

General about the new product proposal screening *(5 -7 minutes)*

1. How does the FFE screening happened in your company?
2. Do you use any decision making tools (software) to evaluate the projects or to make selecting decision? Or compare them with historical data or previous projects.
3. How many proposals do you usually evaluate at once?

Details about screening process (15-20 min)

1. When you get new proposals, when you get a proposal for new product, what kind of information they provide to you?
2. How accurate is this information?

3. How do you start? Or what do you look for when you study the new product proposal?

   Probe Question if the answer was not provided before this point

   a. What are the most important criteria you search for?
4. If you go back to the last project you recommended going with, what were its characteristics?
5. Why did you think it was a good project?
6. What were your specific goals at this time?
7. How did you evaluate that project?

   Probe questions: asked about that certain experience and examples to understand about the process been used.

   a. *Did you put more weight on these (……) criteria over others?*
   b. If the project satisfies some criteria and not others (or you don't have enough information about all criteria) how did you evaluate that project?
   c. *So even though the project was likely not to satisfy this …. Criterion, you recommended it.*
   d. So, you compare these proposals against each other... evaluate them independently

8. Were your decision based on previous experience with the customer, product, company, etc.

   Probe questions:

   a. Which one
   b. How much do you count on this previous experience?
   c. ex. if a new customer come up with project that may bring more profit than an old customer and you have limited time and resources which one would you choose

9. When you give your recommendation to go with this specific project, how did you defend your choice?
10. Were you satisfied with your decision?
11. What are key factors if would be known (or situation would be different) would make you make different decision

12. What was the final evaluation of the project ($, Performance, succeed (How), Cancelled (Why), failed (Why))

Optional probe if we did not get enough answers

  a. Remembering the last project you recommend to reject, why did reject that project?

13. From your experience, did you ever have the feeling that the project was likely to fail and it actually happened (or the opposite)? What brought that feeling? What did you see in that project that other people did not see?

Closing (summary) Questions (5-7 minutes):

After making sure that we understand the process used for project screening, the next optional questions are coming to overall picture of the evaluation.

14. From your experience, what is usually going wrong with the initial project evaluation?
15. How often the company kills projects (or continues on the back burner)? Why (does that because failing in evaluating the project at the beginning or other factors).

PROCEDURE AND ISSUES FOR INTERVIEWS:

1. The goal from the interview template questions is to guide and encourage the interviewee to discuss his experience and skills at recognizing the situation, evaluating the most important criteria, provide us with actual dynamic process of project evaluation.
2. Time needed to finish the interview: In cases of limited time available for interviewing experts, questions should be prioritized to focus on understanding strategies bases for decisions in evaluation proposals. This can happen by encourage interviewee to talk about previous experiences and reflect on them.
3. Interview will take the dialog form, which means that questions may not be asked in the same order, using the same words.
4. If the interviewee cannot come up with case immediately, several cases might be briefly discussed that participant would pick up one case and go from there.
5. Ask the interviewee to draw sketches or graphs to present the steps, or to provide his own notes, decision tree, etc.

EMAIL LETTER SENT PRIOR THE INTERVIEW

Dear……..

Thank you for your interest in my dissertation research on the …..

Your contribution will defiantly add value to the study, which I value and appreciate.

Through this interview I am seeking comprehensive description of your experience in screening project concept at the very early stages. I hope you will be as accurate and comprehensive on how do you make these decisions, including all your thoughts, feelings, behaviors, as well as situations and evidence that you experienced. You may recall some evidence; share your personal notes, journals or other ways in which you used and recorded your experience. You may use flowcharts, drawing or writing to provide further explanation.

This interview will be recorded, and all information will be in complete confidentiality and used just for research purpose.

I really appreciate your commitment of time and efforts.

Sincerely,

Fatima Albar

APPENDIX D- INFORMED CONSENT FORM

Dear Mr. / Ms.

You are invited to participate in a research in a research study conducted by *Fatima M. Albar* from Portland State University, College of Engineering and Computer Science toward her PhD degree in Engineering and Technology Management, under the supervision of *Dr. Antonie Jetter, where the r*esearcher seeks to study the process of evaluating new product/project at the fuzzy front end.

Because of your experience in evaluation projects at the very early stages, we are looking to conduct an interview with you lasting 60-90 minutes. Through this interview, we seek a comprehensive description of your experience in screening project concepts at the very early stages of product development. We hope you will be as accurate and comprehensive on how you make these decisions, including all your thoughts, feelings, behaviors, as well as situations and evidence that you experienced. You may recall some evidence, share your personal notes, journals or other ways in which you used and recorded your experience. You may use flowcharts and/or drawing or writing to provide further explanation. However, you will not be asked to reveal any information about a specific project or to name any projects, individuals, or companies.

This interview will be audio recorded for the purpose of this research. Any information that is obtained in connection with this study and that can be linked to you or identify you will be kept confidential; the names of the participants, projects and the companies will be coded and all data will be deleted after we are done with the research analysis. Your contribution will definitely add value to the study, which I value and appreciate. This study is important to because it will help increase system science knowledge about new product evaluation, and it will result in proposing a new decision model to be used to train non-expert managers. Although your participation is appreciated, you need to know that your participation is voluntary, and if you do not want to take part in this study, it will not affect your relationship with Portland State University.

If you have concerns or problems about your participation in this study or your rights as a research subject, please contact the Human Subjects Research Review Committee, Office of Research and Sponsored Projects, 600 Unitus Building., Portland State University, (503) 725-4288 / 1-877-480-4400. If you have questions about the study itself, contact *Fatima Albar* at *albarfm@pdx.edu*.

Your signature indicates that you have read and understand the above information and agree to take part in this study. Please understand that you may withdraw your consent at any time without penalty, and that, by signing, you are not waiving any legal claims, rights or remedies. A copy of this form will be provided to you for your own records.

Sincerely,

Fatima M. Albar

______________________________ ____________________

Signature Date

APPENDIX E- CODEBOOK

Class	Coding Node	Description	Look Up Words	Example	Frequency	Notes
Criteria	Business Scope	Does this project fit with company business scope?	Line up with other products, core business, company's values and believes	I struggled for a while because this investment is not within our core business	14	
	Company Portfolio	How many similar/ different projects in the company portfolio?	Company portfolio, how many projects with the same size, projects pipeline	Your portfolio should contain a bunch of high risk high payoff, medium risk maybe medium to low payoff, and then sure things you got to do and you got to get into production	10	
	Product Concept	How good and coherent is the product concept? Does it	Solid idea, good idea, good features, it's different,	Why my product is different?	52	

Class	Coding Node	Description	Look Up Words	Example	Frequency	Notes
		appear desirable?				
	Creating a New Norm	Are creating a new norm? New customer expectation ?	Will be expected, evolution	It was so successful, that most people are pissed off if they go anywhere in the civilized world and open up their laptop and there's not connectivity. I mean, it's just expected.	7	Not in Literature
	New Idea	Is it a new idea? New innovation	It is new, very creative, innovative	We knew technically how They work in general idea. But it has not been done before	14	
	Credibility/ Reputation of the idea proposer	Who's proposing this project? What is his (their) success history	Credibility, experience , reputation of the proposer	I mean the first thing that comes to mind is who is talking to me; do I trust this person's recommendation?	38	Not in Literature
	Preservin	What is the	Look fool,	There's another	5	Not

Class	Coding Node	Description	Look Up Words	Example	Frequency	Notes
	g ones Credibility	impact on the manger when he promotes the idea?	look bad,	dimension to it where you don't want to be a fool relative to other people on the panel.		in Literature
	Brand Reputation	Will it affect the trust on the brand	Brand reputation , customer trust	I don't want to lose my reputation with my brand that the people trust by making horrible project.	3	Not in Literature
	Customer Needs	Does it solve customer problem? Fulfill function not provided now or fulfill it better?	It solve a problem, fit customer needs,	That great innovation starts with understanding your customers' needs and desires	43	
	Technical Feasibility	Are the production technology	Feasible , know how to do it,	Have the technology or at least have the knowledge to make it	63	

Class	Coding Node	Description	Look Up Words	Example	Frequency	Notes
		and skills available?	can do it			
	Technology Significance	How big the contribution to technology?	Innovation, creative technology, apply tech in to diff applications or products	The main goal out of this product was to use the same technology in another high end …	15	
	Risk	How much uncertainty in bringing it to market?	Risk, financial risk, marketing risk, manufacturing risk	I took the risk knowing we had the time.	19	
	New Market	Is it a new market? Is it a new market for me?	How much do I know about this market? Am I familiar with this	But it was completely new market for us	4	

Class	Coding Node	Description	Look Up Words	Example	Frequency	Notes
			market?			
	Market Opportunity	How big is the market size of these products? How big is the market share I am aiming to get?	Market size, market share, know the market	How big is the market size of these products? How big is the market share I am aiming to get?	30	
	Market Growth	Is this market growing	Market share, market growth	It is huge market that is growing	7	
	Profitability	Is it profitable?	ROI, revenue, pay back	He showed me some estimation for a good return of investment	23	
	Competitors	Who do we have to compete with?	Competitors, other brands in the market	What are other products in the market that are close to this product?	31	
	Size of	How big is	Cost,	How big is the	11	

Class	Coding Node	Description	Look Up Words	Example	Frequency	Notes
	Investment	this investment?	economically acceptable, small/ large investment	investment?		
	Fund	Can investment required be obtained?	Fund, budget, affordable	The first question is: can I find it out of my budget?	20	
	Resources	Do we have / can have the needed resources?	Infrastructure, have the resources, suppliers , materials, tools	If you come up with a cost, then what resources are going to be needed, you know, to actually design and, you know to build it?	13	
	Manufacturing time and Process	Time and process needed to make the product?	Number of process, production time	How many leaps of faith it requires, the lesser the better?	8	
	Future State of	How the economy	When the product is	So another category would be I spend	3	

Class	Coding Node	Description	Look Up Words	Example	Frequency	Notes
	Economy	will look like in the next coming years when the product hit the market?	ready, the economy for the next few years	some time trying to anticipate the future		
	Personal Interest or Enthusiasm	Any mentioning for a decision or implying preference of a choice over another		Here, let's do it this way, this idea, you know, here's what I think the market potential is, here's what I think the revenue potential is, here's what I think the margin potential is, Interviewer: All those are just estimations… Interviewee #1: Here's why I think we should do it, it leverages a few strings, whatever,	40	Not in Literature

Class	Coding Node	Description	Look Up Words	Example	Frequency	Notes
				blah blah blah blah blah. The next thing you have to do is forecast an investment stream. And along with the investment stream you have to forecast a revenue stream.		
Decision	Decision Process	Describing decision making order, process or steps		This is the first step and actually the one that I think sometimes people will take too long to get through, you have to first be clear in your own mind that you need to make a change and very often that question in itself, I think that's the first step in the decision process is becoming very clear in your	43	

Class	Coding Node	Description	Look Up Words	Example	Frequency	Notes
				own mind that you have to do something different		
	Decision Case	The story, case or a project the interviewer mentioned		Ok, a product has been proposed to make a new piece of technology (I don't to go through the details) ... the product concept was good, it sounds solid and it is achievable, we can make it. the proposer thought that we have the ability to market it through the same channels we market our current products, we just need to advertise for it as we advertise for any new products, and he show me some estimation for a good	66	

Class	Coding Node	Description	Look Up Words	Example	Frequency	Notes
				return of investment... it sounded good, but I struggled for a while because this investment is not within our core business, we are not familiar with this market. On paper it seemed good but I could not feel it, I didn't think it is the right thing to do. From my pervious experiences.		
	Heuristic-Recognition	Make a decision depending on recognizing or not recognizing the idea by the decision		I think people make that mistake too because going with the thing you know is the easiest and I have done that at least once	16	

Class	Coding Node	Description	Look Up Words	Example	Frequency	Notes
		maker				
	Heuristic-EBA	Eliminate the project because a certain or multiple reasons		So, even though it was a good idea it doesn't fit with what we are looking for	16	
	Heuristic-Categorization	Categorize this project under certain group or class		Things that are possible there are things that may be could happen, and then there is things that you kind of know it is not going to happen	7	
	Heuristic-Conjunctive	Evaluate the pros and cons to a level of satisfaction to make a decision		We don't have a formal process for that, we don't have, my vote is worth so much, it's a collaborative process, but ultimately at the end of the day I think if can't reach a	10	

Class	Coding Node	Description	Look Up Words	Example	Frequency	Notes
				consensus it's likely we're going to probably say no. We have to really be able to reach alignment on whether this makes sense or not, and if we can't then it's probably not for us.		
	Heuristic-Tallying	Evaluate all the pros and cons of the project		I am not into this market, I don't know much about it	10	
Decision Behavior	Gut Feeling	The way he thinks, feel or believe about making decision	Gut, intuition, feeling, vision, guts	Some people will have some feeling more for some ideas than the others	45	
	Experience	Compare to cases from previous experience	Experience, I saw before, I learnt this	From my pervious experiences......I did not trust this idea	25	
Othe	FFE	Featured of		It always works if you	28	

Class	Coding Node	Description	Look Up Words	Example	Frequency	Notes
r Nodes		fuzzy front end stage		know everything, but by the time you get all the data, the data's nine months old so you don't really know what to do.		

APPENDIX F- CRITERIA USED BY RESPONDENTS

Criteria	R 1	R 2	R 3	R 4	R 5	R 6	R 7	R 8	R 9	R 10	R 11	R 12	Respondents	frequency
Business Scope	1	2				1		5	1	1	1	2	8	14
Company Portfolio	3		1	4		1		1					5	10
Competitors	3	3	1	1	2	3	2	2	2	3	5	4	12	31
Creating a New Norm	2	1		1		1				2			5	7
New Idea	1			1	1	2	1		1	1	2	4	9	14
Reputation of The Idea Proposer	3		2	1	3	4				4	5	16	8	38
Preserving Ones Credibility	1			1						3			3	5
Brand Reputation						1		2					2	3
Customer Needs	4	3	5		6	9		4	3	1	1	7	10	43
Future State of The Economy	2								1				2	3
Funding	6	3					2			1		8	5	20
Manufacturing Time and Process	1				1	1	5						4	8
Market Growth	1				1	2			2			1	5	7

Market Opportunity	6	1		4	2	7	1	2	4			3	9	30
New Market	1							3					2	4
Product Concept	3	3	3			7	4	5		7	6	14	9	52
Postponed Project												2	2	3
Profitability	8	1	2	4			2	2	3			1	8	23
Resources	1	5	4			1	1					1	6	13
Risk	7	1	6	1		1			1	1		1	8	19
Size of Investment	4	1		1			3	1				1	6	11
Technical Feasibility	2	13	5	4	1	2	7	3	4	6	5	11	12	63
Technology Significance	3	3					1	4	1	1	1	1	8	15
Number of Unique Criteria	21	13	9	11	8	15	11	12	11	12	8	16		

APPENDIX G- HEURISTICS USED BY RESPONDENT

Heuristics	R 1	R 2	R 3	R 4	R 5	R 6	R 7	R 8	R 9	R 10	R 11	R 12	Respondents	Frequency
Recognition	1	3				3	3	2		1	1	2	8	16
EBA				2	1	1	2		2	1	4	3	8	16
Categorization		1									1	5	3	7
Conjunctive				1	1	1			2	2		3	6	10
Tallying	1	1	3					1		2	1	1	7	10
Number of Unique Heuristics	2	3	1	2	2	3	2	2	2	4	4	5		

APPENDIX H- INTERCODER RELIABILITY

Intercoder reliability is a standard measure of research quality and is considered s a critical component of content analysis [288, 289], even though there are few standards and guidelines available concerning how to properly calculate and report intercoder reliability [290].

Popular methods for establishing intercoder reliability involve presenting predetermined text segments to different coders [291]. Intercoder reliability is achieved when independent coders evaluate the characteristics of a message and reach consistent conclusions when applying the same codebook [290, 291]. In practice, there is always coding disagreements in the coding sample [290]. Neuendorf [292] sets a rule of thumb that declares intercoder reliability at above 80% as being good and from 67-79% as being acceptable. According to Lombard et al. [290]. 90% or greater are always acceptable, 80% or greater is acceptable in most situations, and 70% may be appropriate in some exploratory studies for some indices but it is hard to interpret and call into question the value of replication [293]. The research in this dissertation is inductive and of exploratory nature; the target limit for intercoder reliability is therefore set at 80% or above.

Intercoder reliability is calculated by examining the degree to which coders agree across a fixed set of units [291]. For the purpose of this research percentage agreement has been used as a measurement for intercoder reliability. Percentage of agreement, also known as raw percent agreement or crude agreement, is defined as "the percentage of all coding decisions made by pairs of coders on which the coders agree." [290] page 590. Percentage agreement does not account for agreement that occurs simply by chance, and can be artificially kept high if a large number of codes that are rarely used or rarely disagreed upon are included in the codebook [290]. On the other hand, it counts any coding that does not use an identical, but a conceptually similar code as disagreement, thus potentially over reporting the disagreements [290]. An advantage of the method is its conceptual and computational simplicity and the fact that it can accommodate any number of coders [290]. Moreover, some of its limitations can be addressed through a reliable codebook that contains sufficiently granular and reliable codes. To establish high level of reliability for the codebook, the codebook in this research was pretested and revised by three experts to ensure the clarity of the definitions and the examples as recommended by literature [240, 294].

To insure the quality of this research two processes of intercoder reliability have been applied: coding two whole interviews, and coding different samples from coded segments. Three different coder than the researcher participated in this process

In the first process two complete interviews were coded by the researcher (Coder 1) and a second coder (Coder 2), who was experienced with the topic and the code book. Although this approach is harder and more time consuming than giving sample segments to other coders, it avoids lifting text from its original context, or making interpretations about the length of codable text [291]. The results were compared for the intercoder reliability using NVivo 9 - the qualitative analysis software- by running Coding Comparison Query. The percentage agreement used by Nvivo is defined as the percentage of the source's content where the two users agree on whether the content may be coded at the node. Running the comparison query for the two interviews coded by the

Coder 1 and Coder 2, shows that Coder 1 agreed with Coder 2 on 85% of the codes, thus achieving the desired target value.

For independent sample coding, two different groups of samples segments were prepared. One sample contained examples of decision criteria, which were expected to be easier to code correctly than decision heuristics. The other sample contained text sequences pertaining to different decision heuristics. Splitting the samples ensure that results are not accumulated around decision criteria alone or biased toward any particular type of text. Codes were considered similar only if both coders used identical set of codes. The percentage of agreement was calculated by dividing the number of agreement codes by the total number of codes. The researchers (Coder 1) agreed with Coder 3 on 88% and with Coder 4 on 84% of the codes.

Intercoder reliability of this research is therefore acceptable.